DC-SC INJECTOR FOR HIGH AVERAGE POWER FREE ELECTRON LASERS*

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Abstract

A DC-SC superconducting injector for high average power Free Electron Lasers has been designed in PKU. It consists of a DC extraction gap, 1+1/2 superconducting cavity and coaxial input system. The DC gap, which takes the form of Pierce configuration, is connected with the 1+1/2 superconducting cavity. The photocathode is fixed on the negative electrode of the DC gap. Simulations are made to the beam dynamic of the electron beams extracted by DC gap and accelerated by superconducting cavity. High quality electron beams with emittance lower than 4 π-mm-mrad can be obtained. The optimization and experiments of the DC gap as well as the design and experiments of the coaxial coupler are all finished. An optimized 1+1/2 superconducting cavity is in process of manufacturing.

Key words: injector, superconducting cavity, high average power FEL, Pierce configuration

1. Introduction

In the development of the high average current superconducting photocathode injector, a lot of problems have been encountered. Among those problems, an important one is how to solve the compatibility problem between the superconducting cavity and the photocathode. Based on our experiences[1], a DC-SC photocathode injector is developed in PKU. This injector consists of a pierce gun, a 1+1/2 cell superconducting cavity[2,3], and photocathode is on the cathode of Pierce gun. Figure 1 shows the structure of DC-SC photocathode injector. Thus, the compatibility problem can be avoided. Since the distance between the photocathode and the strong electric field of the cavity is very small, the growth of the emittance is not very serious.

The injector will work at CW mode, the superconducting cavity works at 2K. We hope that injector can provide the electron bunch with the following parameters. Bunch energy: 2~3MeV; Bunch length: <10ps; Bunch charge: 60pC; 90% Transverse emittance (normalized): several pi mm-mrad; Repetition rate: several tens MHz; Average beam current: 1~5mA.

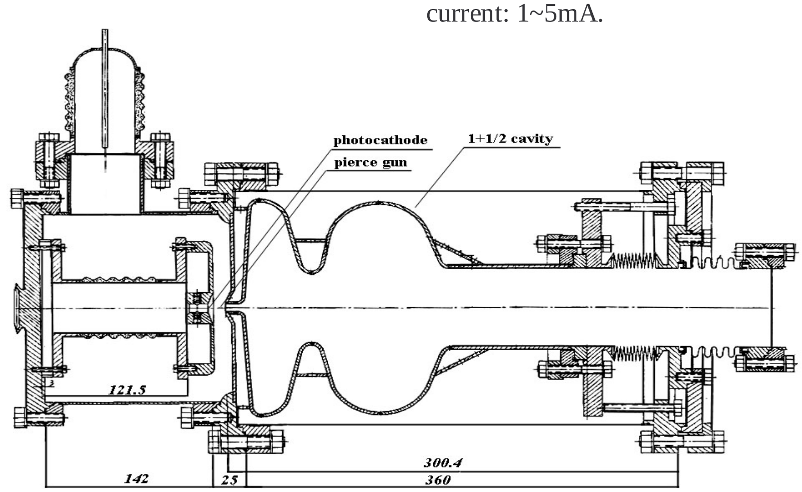

Figure 1: The new DC-RF superconducting injector

2. Computer Simulation

2.1 Optimization of the SC cavity

Code SUPERFISH is used to optimize the cavity. In the optimization of the SC cavity, design of the first half cell is very important. General rules for the

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optimization of the first half cell are stated as following: The accelerating gradient should be as high as possible, thus E_{peak}/E_{cath} and B_{peak}/E_{cath} should be as low as possible.

In order to decrease the distance between photocathode and SC cavity, we use the conical back wall (about 5 degree) instead of a flat back one. This conical back wall changes the distribution of the electric field and adds a focusing ability to the cavity. The geometry of the full cell is based on the TESLA design[4] to simplify the production. By changing the maximum radius of the 1/2 cell, we can change the frequency, E_{peak}/E_{cath} and B_{peak}/E_{cath} of the cavity. By changing the length of the 1/2 cell, we can get a different electric field distribution at a fixed frequency. By changing the radius of iris, we can increase the electric field in the first 1/2 cell.

Considering all the aspects listed in the table 1, we decide to use the following geometry of the first 1/2 cell. Length: 57.7mm; Radius of iris: 34mm; Maximum radius: 105mm; Frequency: 1300.08MHz.

Table 1: Characteristic parameters of SC cavity changing with the shape of the first 1/2 cell

Length (mm)	Radius of iris(mm)	Maximum radius(mm)	Frequency (MHz)	E_{peak} (MeV)	B_{peak} (A/m)	E_{cath} (MeV)	E_{peak}/E_{cath}	B_{peak}/E_{cath}
57.7	35	105.0	1302.76	2.523	4886.86	1.856	1.36	2.63
		106.0	1299.50	2.336	4130.16	1.170	2.00	3.53
57.7	34	104.8	1301.50	2.686	5316.73	2.043	1.31	2.60
		105.0	1300.08	2.489	4795.87	1.911	1.30	2.51
		105.3	1299.26	2.232	4206.93	1.593	1.40	2.64
58.7	35	105.5	1299.97	2.296	4035.07	1.293	1.77	3.12
		105.1	1301.17	2.238	4096.38	1.558	1.44	2.63
59.7	35	105.0	1300.62	2.250	3904.89	1.447	1.55	2.70
		105.2	1300.04	2.287	4009.37	1.318	1.74	3.04
		105.5	1299.34	2.335	4139.50	1.147	2.04	3.61
58.7	34	104.5	1301.60	2.723	5296.09	2.062	1.32	2.57
		104.8	1300.10	2.398	4605.06	1.777	1.35	2.60
		105.0	1299.29	2.198	4179.62	1.604	1.37	2.61

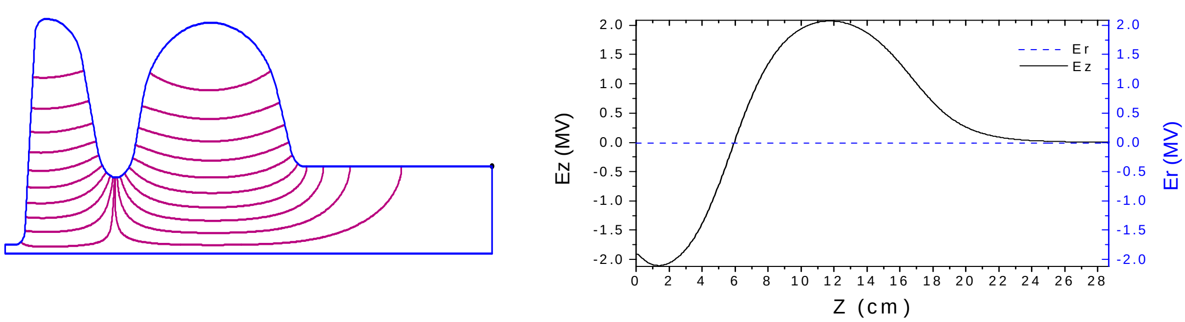

Figure 2: Electric field distribution in the cavity and along the axis

2.2 *Determination of the Pierce gun*

An important parameter of optimizing the extraction structure is the slope angle of the anode nose. It affects the emittance and focusing ability. The smaller the slope angle, the stronger the focusing ability. But the decrease of the slope angle will lead to the increase of the distance between photocathode and superconducting cavity, thus the emittance will grow too much. Since Pierce gun is relevant with SC cavity, the problem of matching between them also should be considered. Changing of the distance between photocathode and SC cavity due to the changing of the anode inclination will surely affect the synchronous

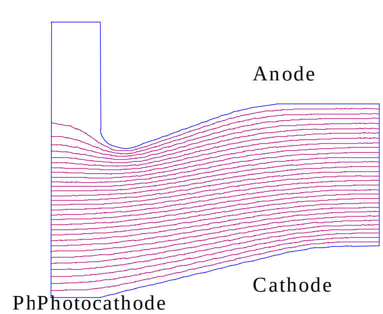

Fig.3: electric equipotential lines in the pierce gun

phase of the SC cavity. Thus the anode inclination and the synchronous phase of the SC cavity should be decided simultaneously through the computer simulation. The simulation results are listed in table 2. Fig4 shows the beam envelope in the injector.

2.3 Simulation of beam dynamics

PARMELA[5] is used to simulate the performance of the whole injector. Initial conditions and the simulation results (optimized results) at the exit of the injector are listed in Table 2.

Table 2: Initial conditions and simulation results

Initial conditions			Simulation results	
Electron bunch	Radius	3.0mm	anode inclination	65°
	Length	10ps	Synchronous phase	-50°
	Charge	60pC	Energy	2.43MeV
	Emittance	0mm-rad	Radius	1.9mm
SC cavity	Average gradient	15MeV	$\triangle E_k/E_k$ (rms)	2.63%
Pierce gun	Distance between cathode and anode	15mm	Bunch Length	7.8ps
			ε_x (90%, n)	8.249mm-mrad
	Cathode voltage	-70KV	ε_y (90%, n)	8.832mm-mrad
	Anode voltage	0KV	ε_z (90%, n)	55.22KeV-ps

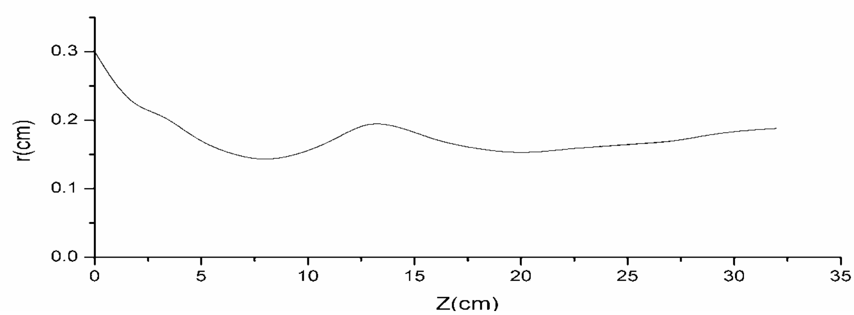

Fig.4: Beam envelope in the injector

3. RF System

A 1.3 GHz, 5 kW, CW mode solid state power amplifier is used for the DC-SC superconducting photocathode injector. The RF power is transferred to the cavity through a coaxial coupler to avoid emittance growth due to the asymmetric field. A phase synchronous system is used to ensure the power amplifier and the laser synchronized.

4. Drive Laser System

Our dive laser is designed to cover the applications for different cathode materials, such as metal, semiconductor and alloy. The wavelength of the seed laser is 1064μm. The pulse energy of UV light will be more than 10nJ. The pulse repetition rate is adjustable from 20 ~ 40 MHz. For restricting the beam emittance growth, the laser-to-RF timing stability is designed of less than 1ps.

5. Conclusion

The computer simulation results show the DC-SC injector is feasible. The test of prototype cavity has been finished, and experiments on the coaxial coupler are completed. The 5kW solid power amplifier is under debugging. The DC-SC injector is under construction now.

6. References

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