DEVELOPMENT OF THERMIONIC-CATHODE RF ELECTRON GUN AT IHEP

Jialin Xie, Jie Gao, Yongzhang Huang, Renshan Zhang, Hongxiu Liu and Youzhi Wang
Institute of High Energy Physics, P. O. Box 918, Beijing, P.R. China

Abstract

A thermionic cathode rf electron gun has been developed in IHEP, Academia Sinica. The gun will accelerate and pre-bunch electrons emitted from a L_aB_6 cathode using a high electric field in a resonant cavity. The gun was fabricated and tested, also used in Beijing free electron laser project. The simulation results of beam dynamics are given and the experimental results are presented.

I. Introduction

As an injector for the linac based free electron laser, rf electron gun has been under active developments in many laboratories because of its capability of producing high current, low transverse emittance, high injection energy and low energy spread electron beam. There are two kinds of cathodes used for generation of electrons in rf gun[1]. One is the photo-cathode which emits electron bunch with width controlled by the irradiating laser pulse. Another is the thermionic cathode which produces relative long electron pulse from the gun and the useful electron bunch width is controlled by magnetic compression and selection of an alpha magnet. The photo-cathode gun gives good performance but the system is complicated and expensive. On the other hand, the thermionic cathode gun gives satisfactory performance for FEL in the IR range, is quite compact and much less costly. This last account explains why it becomes the choice of BFEL project[2]. In the following, section 2 describes the injection system and the gun in particular. Then, in section 3, simulations to predict the behavior of the electron bunch (emittance, phase spread, energy spread, intensity, etc.) and the injector operation characteristic are presented. Lastly, in section 4, experimental measurements of the injector performance of a prototype gun are given.

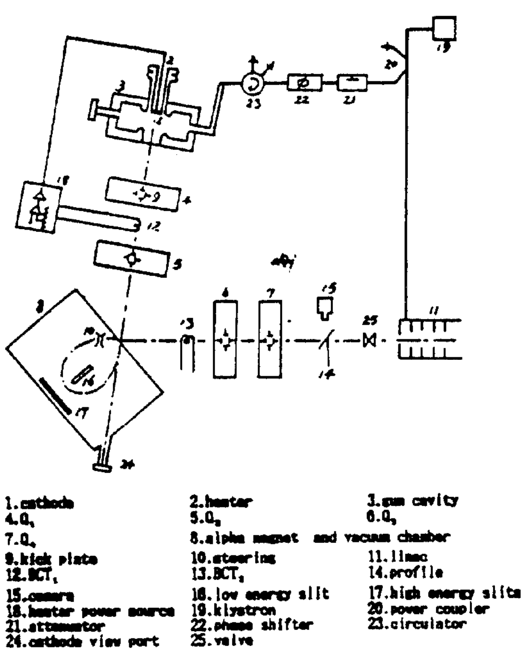

Figure 1: Schematic layout of our rf gun system

II. Description of the Injector System

Westenskow and Madey first developed microwave gun and incorporated it successfully in Mark III FEL at Stanford University [3-4]. Our injector system is similar to theirs except some modifications have been made. As shown in Fig.1, the system consists mainly of a thermionic cathode rf gun as electron source, an alpha magnet for bunch compression and energy selection, four quadrupoles for focusing in the beam transport and intensity and profile monitors.

As can be seen from Fig.2, the gun cavity is a TM_{010}-like resonator with two coupling apertures opposite to each other. One is connected to the klystron for excitation and the other, a cut-off aperture to serve both

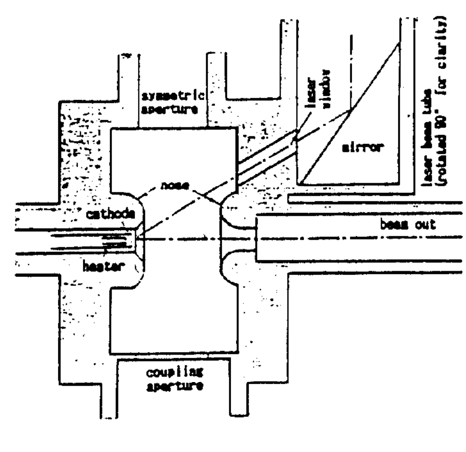

Figure 2: Cross-sectional view of the gun cavity

as a field measurement port and as a symmetric rf field perturbation in order to minimize field distortion along the beam centrline, which will cause emittance growth. There is another hole on its top, through it a laser beam

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can be directed to the cathode for the laser assisted heating to counter the back bombardment problem[5] Furthermore, as another scheme, for back bombardment control, a deflecting magnet field will be used and hence the exit aperture is enlarged to accomodate the exit beam. The cavity was designed with SUPERFISH[6] and URMEL[7] to give resonant frequency and field distribution etc.. The frequency shift caused by coupling aperture and laser was calculated by using MAFIA[8].

At the bottom of the cavity, a single crystal L_aB_6 cathode is used for high emissivity which is further enhanced by the strong rf field at the cathode surface that reduces the work function in the Richardson-Dushman equation.

The alpha magnet[9] is another critical element of the system which is characterized by its achromaticity and non-isochronism. The different path lengths between higher and lower energy electron orbits compress the bunch width and the location and the seperation of the slits define the mean energy as well as emittance, phase spread and energy spread of the beam. Other components of the system are self-explantory and will not be further discussed.

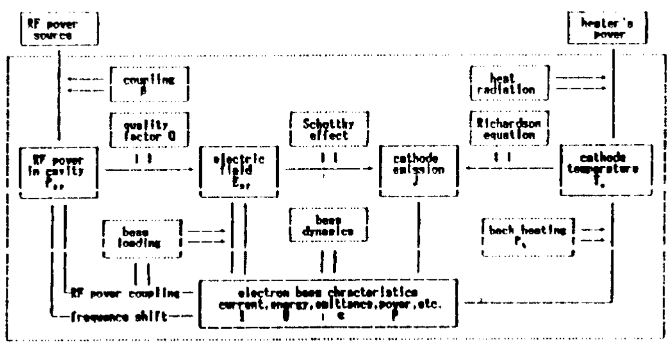

Figure 3: Physical process in the cavity

III. Simulations

The physical processes taken place in the operation of the rf gun and the manner they interact with each other are illustrated in Fig.3. Instead of taking all factors into consideration, some simplified assumptions are made for the simulations of particle dynamics as well as for operation characteristics. For the particle dynamics, PARMELA was used for the injection of "superparticles" and the motion of an electron bunch through an alpha magnet[10]. In the former case, particles are generated in a similar way as for photocathode rf guns but with the main difference that the initial phase of all the particls excluding the reference particle is randomly sampled ranging from 0-180° in half of one rf cycle. according to the Richardson-Schottky equation. The charge amount with these particles can be obtained simultaneously. In the latter case, particles are made to travel through the alpha magnet in a similar way to solve the equations of motion for each particle and then to convert their position and momentuma from the local coordinate system for the alpha magnet itself to the one for the whole injector.

The mesh method was used to include the space charge force in the simulation. Although the alpha magnet in the injector is not linear itself, we believe that the bunch length is short enough to cause no significant error in any segment of an alpha-shaped trajectory when the bunch is passing through it. The image charge force, beam loading and wake field were not included in the simulation. The parameters used for simulation are given in Table I.

Table I. Element Parameters Used in the Simulation

Elements	z (cm)	Strength
Gun Cavity	0 — 3.45	35 MV/m
Quadrupole 1	14.5 — 18.9	-50.2 G/cm
Quadrupole 2	25.8 — 30.2	40.42 G/cm
Alpha Magnet	40.9 — 365.5	184.0 G/cm
Quadrupole 3	81.6 — 86.0	65.0 G/cm
Quadrupole 4	91.8 — 97.4	-56.0 G/cm

Note: the slit is located at 53.2 cm with width 0.4 cm.

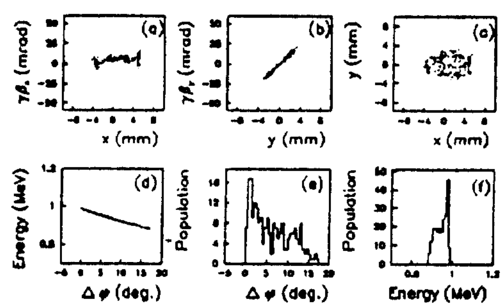

Figure 4: Dynamic properties of the bunch at the entrance of the linac.

For the operation characteristics, we want to see how the rf fields in the cavity affect the energy, the current, the emittance, the length and the power of the electron bunch. Ronga Kutta method is used to integrate the motion equations for getting the trajectories of electrons. From the information of many electrons, we have the beam characteristics. The radial space charge force is considered in the computation program. The beam loading effect is considered in the program by the method of iteration. It is important to note that the results of computation, because of various approximation made, can only indicate qualitatively the experimental behaviour.

For the results of simulation, Fig.4 gives the dynamic properties of the bunch at the entrance of the linac. Fig.5(a) is the output current versus the cathode temperature for several rf power absorbed in the cavity. To show beam loading effect, Fig.5 (b) is the curves of peak energy gain versus output current for several absorbed rf powers.

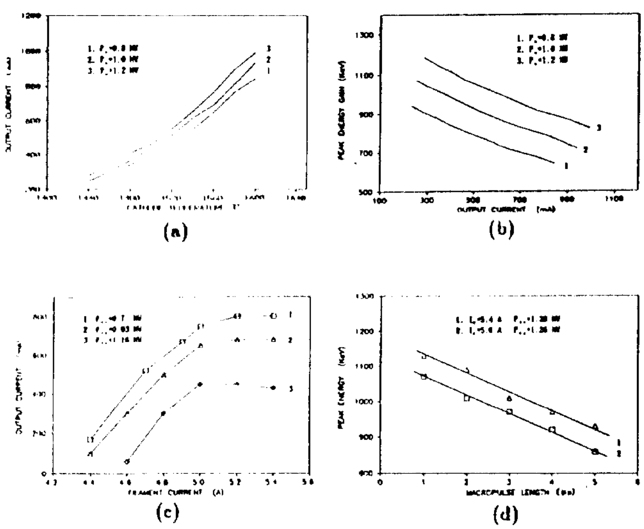

Figure 5: Simulation and measurement of the operation characteristics. simulation: (a) output current vs. cathode temperature, (b) peak energy gain vs. output current. experiment: (c) output current vs. filament current, (d) peak energy vs. macropulse length.

IV. Experimental Results

The operation characteristics of the injector are given by the following figures. Fig.5(c) shows gun current versus filament current for several rf powers input into the cavity. The Schottky effect can be seen in the figure that the output current is higher while the rf power (or the electric field strength) in the cavity is increased. The beam loading effect together with the back bombardment effect can be seen in Fig.5(d). which gives the peak energy versus the macropulse length, a longer macropulse results in more current and lower energy. The performance of the system as demonstrated by the above figures is apparently in qualitative agreement with the simulations. Table II summarizes the performance of the prototype rf gun injection system. It should be noted that the emittance might not be the ultimate values because some mechanisms causing emittance growth have not been taken care of in the initial tune-up.

Table II. Performance of the Prototype RF Gun Injection System

from the gun cavity	macropulse length	6 μs
	macropulse current	0.7 A
	maximum energy	1 MeV
Injection to the linac	macropulse current	200 mA
	beam energy	0.8 — 1 MeV
output from the linac	current	200 mA
	energy	20 — 30 MeV
	emittance ϵ_{nx}	50 $\pi mm - mrad$
	emittance ϵ_{ny}	40 $\pi mm - mrad$

Acknowledgement

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