Design Study of a High-Brightness Electron Gun for Free-Electron Lasers

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Abstract

A high-brightness electron gun which will be installed in the LINAC for projected FEL experiments is designed. The design whose emittance is limited by a cathode temperature is possible with a thermionic cathode of medium size and a relatively low cathode-anode voltage. Design strategy and results are presented in this paper.

1. Introduction

Free-Electron Lasers (FELs) require high brightness electron beams. We have improved a LINAC at the Nuclear Engineering Reserch Laboratory of the University of Tokyo to produce high quality electron beams for projected FEL experiments. As a part of this improvement, a high-brightness electron gun which will be installed in the LINAC is designed.

In our FEL project, the wavelength of the radiation is in far-infrared region of the spectrum, so requirement for electron beam quality is not so strict. However, it is favorable to make emittance at the exit of the electron gun as low as possible because degree of beam brightness deterioration strongly depends on the quality of the beam at the injector. Computer simulations have been done using the SLAC Electron Trajectory Program.

2. Electron Gun Design

The new electron gun operates in conditions that the cathode-anode voltage is 90[KV] and the beam current is 0.5–1[A]. We use a Y-646E cathode assembly which has a 1.0[cm^2] dispenser cathode. The shape of the Wehnelt electrode, the distance from the cathode to the anode, and the shape of the anode electrode have been adjusted as design parameters.

Since the beam current is 0.5–1[A], the defocusing effect caused by the space charge force is not so large. In this case, if the beam focusing by the Wehnelt electrode is strong which is usual in ordinary electron guns, electron trajectories of the outer part of the beam become crossing with those of the inner part. The beam emittance gets worse, besides the distribution of the current density becomes like that of a hollow beam. On the other hand, if this focusing is too weak, the beam radius at the exit of the gun becomes large and the emittance growth in downstream components due to nonlinear radial fields is expected.

Laminar transport of the beam and maintaining small beam radius at the exit are both important in the design of the high-brightness electron gun.

The lowest value of the normalized emittance of the thermionic cathode limited by thermal motions of the emitted electrons is written as

$$\varepsilon_{n,min} = 2.6\times10^{-2}\pi r_c\sqrt{T} \quad [mm-mrad]$$

where r_c is a cathode radius and T is a cathode temperature. It is no use to design the gun which has the emittance lower than the above value. In our case, the normalized emittance can be made to be less than this limit ($4\pi[mm-mrad]$), so we have tried to make the beam radius as small as possible with the condition that the normalized emittance is almost equal to the lowest limit. We show the shape of our design in Fig.1, the beam distribution in the phase space in Fig.2, and the radial current density distribution in Fig.3. The normalized emittance of this gun is $4.5\pi[mm-mrad]$ and the beam radius at the exit is $1.4[mm]$.

Preliminary calculations of the improved accelerator using PARMELA show the brightness of the accelerated beam with the new gun is increased more than ten times of that with the previous one (Y-796).

4. High-Brightness Electron Gun

For short wavelength FELs, the higher-brightness electron beams are needed. To meet this requirement, it becomes necessary to use the high current density cathodes such as photoemission cathodes to maintain the cathode radius small and reduce the lowest limit of the normalized emittance. We have preliminarily designed a high current electron gun whose current is $5[A]$ changing the cathode radius and the anode voltage in addition to the parameters of section 3. The small cathode and the high cathode-anode voltage are both effective to reduce the normalized emittance and the beam radius. In Fig.4, we show the shape of the electron gun with the cathode-anode voltage of $500[KV]$ and the cathode radius of $1.5[mm]$. The normalized emittance of this gun is $1.7\pi[mm-mrad]$ and the beam radius is $1.6[mm]$.

5. Conclusions

For the electron guns with small beam current, the Wehnelt electrodes with the strong focusing effect are not suitable for high quality electron beams. To produce the electrons from the small area and to transport to the exit laminarly are important. With this strategy, we have designed the high-brightness electron gun for our LINAC for projected FEL experiments.

To realize higher-brightness beams, the small cathodes and the high cathode-anode voltage are effective. The development of the high current density cathodes is very important in this respect.

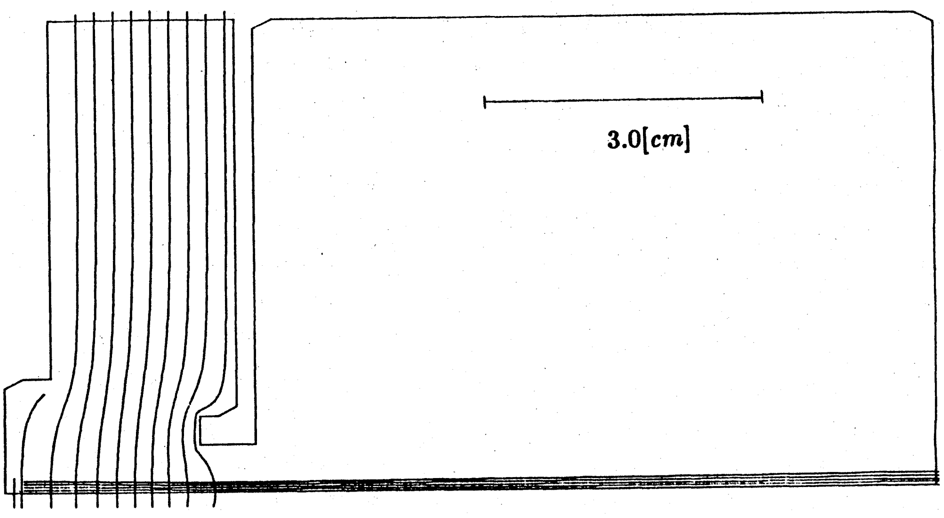

Fig.1 Shape of the new electron gun
and electron trajectories
(the beam current 0.7[A])

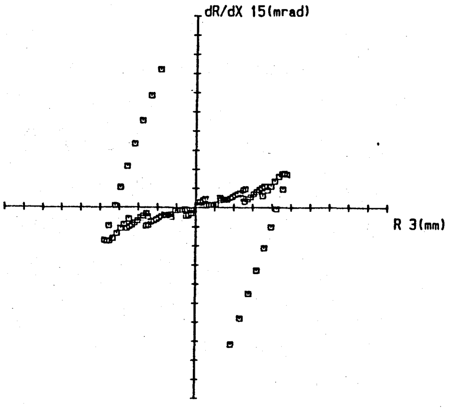

Fig.2 Beam distribution
in the phase space
of the gun shown in Fig.1

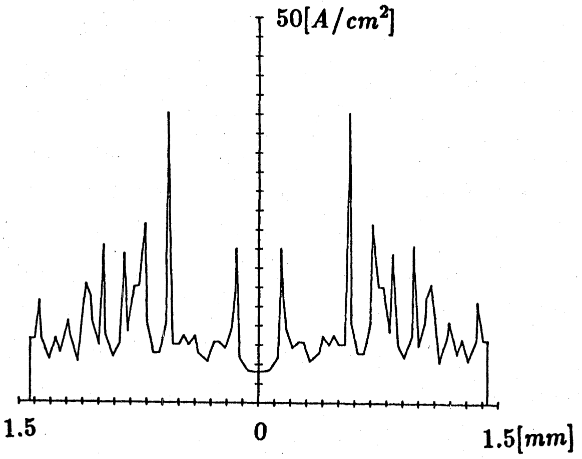

Fig.3 Radial current density distribution

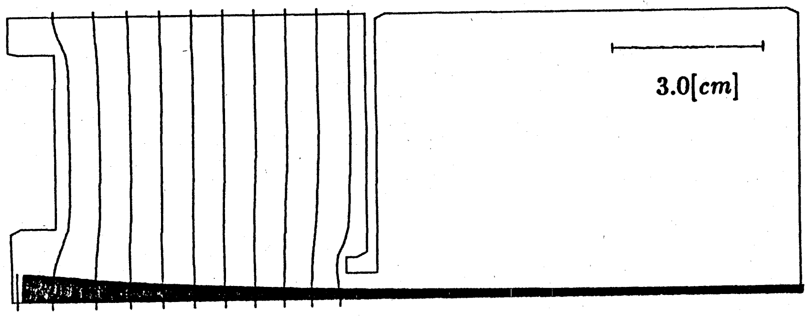

Fig.4 Shape of the higher-brightness
gun and electron trajectories