Design of the electrode shape of the injection gun for the JAERI Free Electron Laser

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ABSTRACT

The newly developed electron gun for JAERI free electron laser should have a good emittance, $< 10\ \pi$ mm mradians, with the moderately high peak current, ≈ 100 mA. To realize such a condition using the conventional electron cathode, we employ a low perveance type electrodes with the small cathode diameter. The function of the electrodes corresponds to the strong focusing followed by strong defocusing action.

1. INTRODUCTION

The essential requirement for the injectors used for the free electron laser is the high brightness, and under the limited peak current it means the low emittance, such as less than $10\ \pi$ mm mradians for our purpose. There are some novel techniques to obtain a good quality beam[1]: photoemissive cathode using pulsed laser excitation and/or RF acceleration immediately after the cathode. However, it can be also realized by using the conventional thermionic emitter, as far as the current density is not too high , ≈ 10 A/cm^2 or less. In our case, the peak current would be less than ≈ 100 mA and the beam diameter ≈ 1 mm, so we tried to design the shape of the electrodes for the injection gun, which satisfied the required condition.

2. DESIGN STUDY

The primary object of the design of the electrode shape is to realize the low emittance beam ($\approx 10\ \pi$ mm mradians) under the condition: energy 300 keV, peak current 100 mA, and beam diameter 1 mm. Firstly we must make a decision to pick up the low perveance type electrode form with an axial symmetry to satisfy such a low emittance. Secondary we chose the beam envelope between the cathode and the anode. There are two types of beam extraction with low emittance: i) the beam is almost parallel to the axis of symmetry, and it has small diameter at the cathode area with the high current density. ii) the beam is focused into anode hole and it becomes almost parallel after extracted from the anode. The later case would be preferable from the point of view about the load for the cathode, but the former one is better when the high peak current is needed and the space charge effect is untolerable.

In any cases, the shape of the electrode must have the characteristics to reduce the unnecessary growth of the emittance between the beam extraction line: the radial component of the electric field formed by the electrodes is proportional to the radial coordinate[1]. If the beam is not extracted, such a condition is easily fulfilled by solving the Laplace equation, but actually the self–field of the beam makes difficult to solve the problem. The design was done by using the SLAC electron trajectory program[2], with minimal modifications about input data handling routines.

The calculations of the electron trajectory were undergone by changing the parameters: a) cathode radius, b) shape of the focusing electrode, c) distance between cathode and anode, d) shape of the anode. The calculations with different current density and the anode voltage were also done.

3. RESULTS

The optimal shape of the focusing electrode is fairly independent of the other parameters, and has a large focusing strength parameter. The anode shape gives less effects to the final results but it must have a defocusing characteristics.

The obtained emittance is exponentially decreased by decreasing the cathode diameter. To satisfy the beam diameter after extraction, the cathode diameter should be less than 4 mm. The radial distribution of the electrons has generally a peak at the edge, so it is like a hollow beam. This is caused by the space charge force inside the beam. In fig. 1, the shape of the electrode and the equi–potential lines are drawn. The filled area near axis shows the beam trajectory from the virtual cathode. In fig. 2a), the normalized current density at each radial point is plotted. Fig. 2b) shows the tangential directions of each ray at the exit of the problem region.

The increase of the emittance becomes linear about the decrease of the anode voltage between 200 and 300 keV, however in this region the required condition is always satisfied.

REFERENCES

1) J.S. Fraser, R.L. Sheffield and E.R. Gray, Nucl. Instr. and Methds A250 (1986) 71.

2) W.B. Herrmannsfeldt, SLAC 226 (1979).

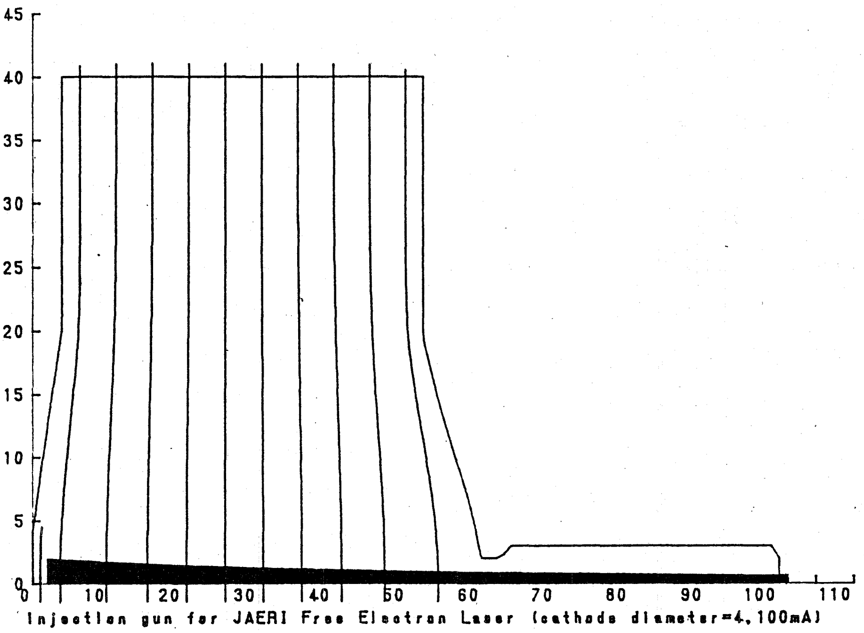

Fig. 1. Shape of the problem region boundary and the equi–potential lines for the cathode with 4mm diam and 100 mA peak current. The filled area near axis shows the beam trajectories from the virtual cathode. Unit is shown in mm.

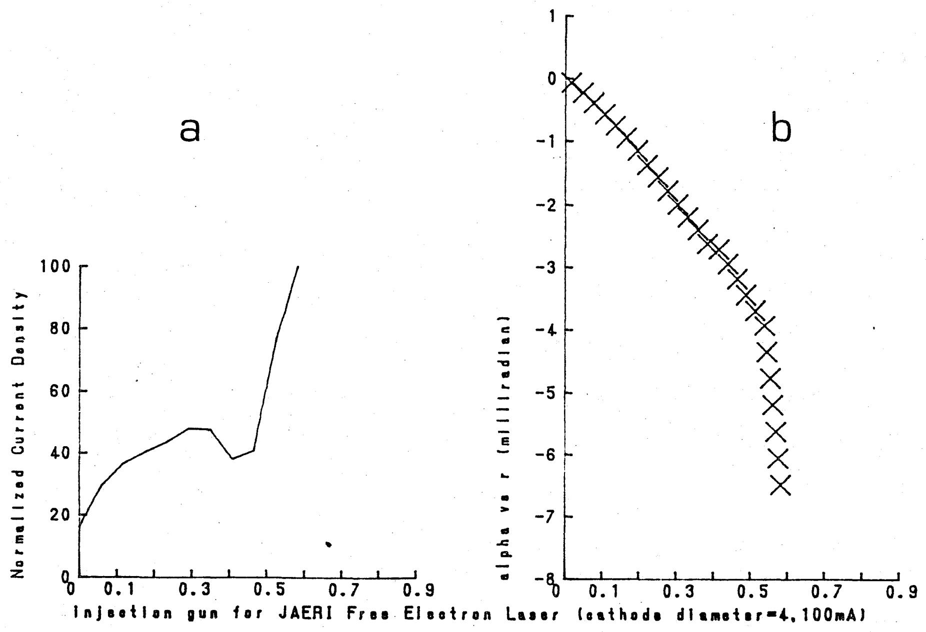

Fig. 2. a) Normalized current density as a function of radial point.
b) Tangential direction of each simulated trajectory.