DEVELOPMENT OF S-BAND RF-GUN IN WASEDA UNIVERSITY

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Abstract

Low emittance and ultra-short electron beam is expected to be used in a wide field, such as free electron laser, laser acceleration, femtosecond X-ray generation by Inverse Compton scattering, and pulse radiolysis, etc. Photo-cathode RF-guns have recently been used to produce the low emittance and ultra-short electron beam. A 5 MeV RF-gun driven by laser is to be developed in Waseda University. The RF-gun is applied a high accelerating field to reduce a space charge effect. We have investigated the relation among the strength of RF field, laser spot size on the cathode and space charge effect in transverse and longitudinal phase space for the so-called BNL type S-band RF-gun by performing the numerical simulation.

1 INTRODUCTION

Ultra-short and low emittance electron beams are indispensable tool for the physical chemistry investigation in ionization and excitation processes of various kinds of materials. Further, high quality X-ray beam with the pulse length of the pico- to femtosecond time region can be generated by the Inverse Compton scattering process between a high-brightness short pulse laser light and a high quality electron beam [1-3].

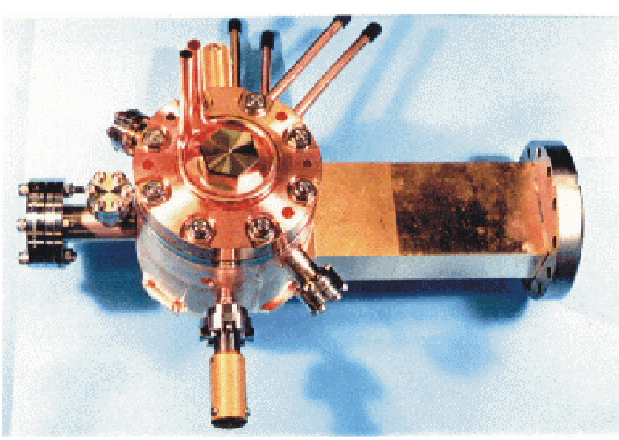

Figure 1: Top of view BNL type RF-gun

In the recent years, the laser driven photo-cathode RF-gun attracts the interest of all over the world as a system, which can generate the very short pulse electron beam with the low emittance not to be possible to achieve in the past.

At present, we are planning to perform the various physical and chemical experiments using the high quality electron beam at Waseda University [4]. In this year, we will install a laser driven photo-cathode RF-gun, and the characteristics of the electron beam will be measured using various tools precisely. After the completion of the beam tests, the experiment of a high brightness X-ray generation will be carried out applying the Inverse Compton scattering process.

In our experiment, Mg cathode, which is developed at Brookhaven National Laboratory, is to be used getting the high quantum efficiency [5]. Using this Mg cathode, it is possible to get a current larger than 2nC per bunch. To decrease a space charge effect due to the high current beam, we will apply the high field gradient up to 150 MV/m.

We have started the simulation work to know the characteristics of output beam from the RF-gun. In this paper we will present some of recent results by the simulation using MAGIC code [6][7].

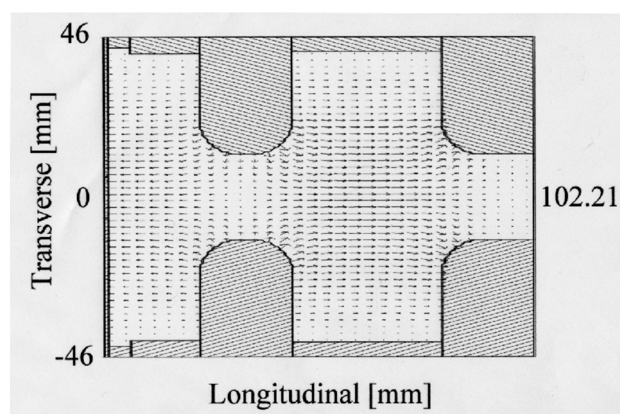

Figure 2: Cross-section of Calculated Cavity (TMπmode: 2856.25 MHz)

2 SIMULATION

RF gun using for our simulation is based on BNL gun-IV, which is 1.6 cells S-band cavity structure. Figure 2 shows the cross-sectional view of the RF-gun with the π-mode resonance at 2856MHz calculated using MAGIC code.

For the first step of the simulation, we examined the optimum condition for the transverse emittance changing the injection phase of the laser to RF electric field under the conditions noted in Table 1.

Figure 3 shows the example of the transverse phase space distribution of output beam from RF-gun. In this case, laser spot size (ϕ) on the cathode was 1.2 mm, and the output beam parameters (energy, normalized emittance, and bunch length) were shown in Table 2.

Table 1: Main parameters

Laser wavelength	266 nm
Laser pulse shape (Longitudinal/Transverse)	Gaussian/ Rectangular
Laser width (FWHM)	10ps (σ.4ps)
Laser spot size	1.2mm
Max. electric field (Half-cell)	93 MV/m
Max. electric field (Full-cell)	107 MV/m
Resonant Frq. (π mode)	2856.25 MHz
Resonant Frq. (0 mode)	2850.91 MHz

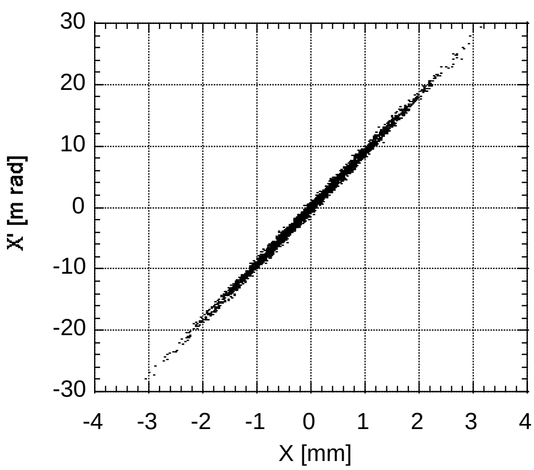

Figure 3: Emittance distribution of output beam from RF-gun

Table 2: Output beam characteristics with laser injection phase at 45 degree

Charge	1 nC
RMS-Emittance	3.07 mm mrad
Kinetic Energy	4.5±0.04 MeV
Bunch Length (FWHM)	10 ps

The relations between the normalized RMS-emittance and an average energy of output electron beam with 1nC charge as function of laser injection phase is shown figure 4.

From this result, we could find that transverse emittance was lower than 5 mm mrad with injection phase between 30 to 75 degrees. Here, injection phase of 90 degree corresponds to the maximum electric field on the cathode.

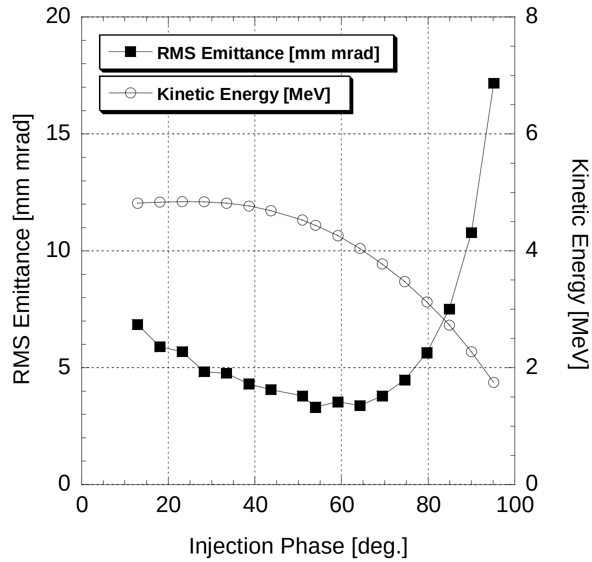

Figure 4: Laser injection phase vs rms-emittance and kinetic energy

In the second step of simulation, we have performed the calculation of the transverse emittance for the output beam with three different gradients of electric field (100, 150, 200 MV/m) as function of bunch charge. The relations between the bunch charge and the emittance of the output beam are shown in figures 5 and 6 under the conditions of laser spot size with 1.2 mm and 2.4 mm, respectively.

In the Figure 5, we can see that the electric field gradient and the transverse emittance have strong relation in high current region above 1.5 nC. In the case of 3nC, the transverse emittance with high gradient case (200 MV/m) is smaller than that with low gradient case (100 MV/m). Thus, in high current case, high field gradient can reduce the emittance growth due to the space charge effect.

However, in the case of low current below 1.5 nC, we could not observe the apparent difference for the three cases of accelerating field gradient as shown in Figure 5. In this case, we may suffer the emittance growth due to the electric field in radial direction in the RF-gun cavities.

To ensure the effect of radial electric field component, we have calculated the case of a twice laser spot size (2.4 mm) on the cathode. In the case of large transverse beam size, the effect of transverse kick due to the radial component of electric field will be enhanced. Figure 6 shows the calculation results. In the case of low current beam, the transverse emittance applying high electric field is larger than one of the low gradient case.

According to these simulation results, it is found that the high acceleration gradient gives better result for the transverse emittance in the cases of the high current above 1.5 nC with beam size of 1.2 mm on the cathode. However, in the case of large beam size, we found that the electric field in the radial direction may induce the emittance growth compare to the space charge effect. In other words, the beam size and the electric field in the radial direction have strong relation. It is found that the optimum electric field exists for each bunch charge and beam spot size.

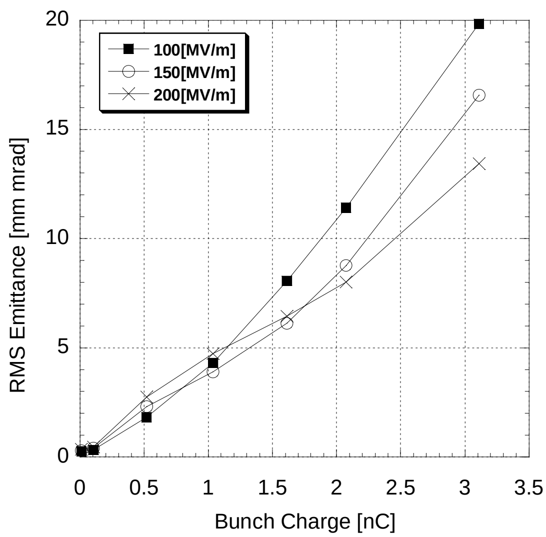

Figure 5: Output Beam Emittance from RF-gun with Beam size 1.2 mm (ϕ) changing Charge and Field Gradient.

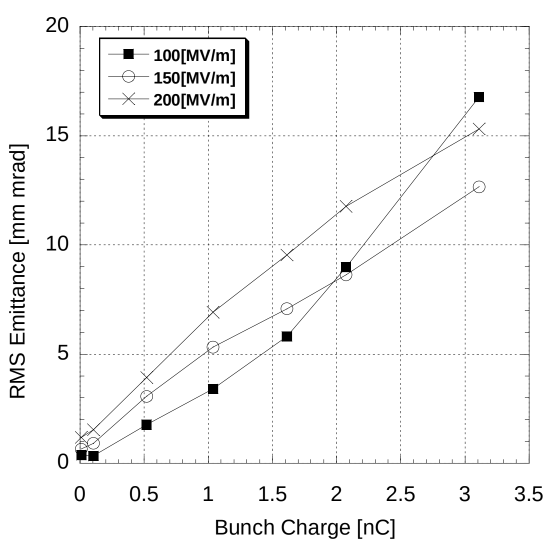

Figure 6: Output Beam Emittance from RF-gun with Beam size 2.4 mm (ϕ) changing Charge and Field Gradient.

In our simulations, we have treated the projected emittance at the exit of RF-gun. To examine the transverse emittance growth due to the electric field in radial direction in detail, we need to consider the slice emittance in a bunch. Because the transverse kick due to radial component of electric field is different with longitudinal position in a bunch. Especially, it is very important under the high accelerating field. As the next step, we will make clear the relation between transverse emittance and electric field strength.

3 SUMMARY

We have performed the numerical simulations for the BNL type S-band RF-gun. From the results of these simulations, we found the suitable range (from 35 to75 degrees) of the laser injection phase RF electric field to get the small transverse emittance. Furthermore, we have examined the high gradient acceleration of RF-gun with different bunch charges. From these simulations, we found that transverse emittance growth due to the electric field in radial direction could not neglect in the case of high gradient acceleration. We will do more careful analysis taking account of slice emittance to clarify the relation between transverse emittance and electric field strength.

ACKNOWLEDGEMENT

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