RESULTS OF SPring-8 RF GUN

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Abstract

A photo cathode RF gun has been studied in SPring-8 in order to generate high density, short pulse and low emittance beam. We constructed an experimental apparatus and also have developed a simulation code to make a comparison with experimental results. In this report, we present comparison results to make sure accuracy of our simulation code, then using this simulation code, we discuss how to reduce the beam emittance of our experiment apparatus. Results of high power test for several different cavities are also mentioned.

1 INTRODUCTION

A photo cathode RF gun has been studied in the SPring-8 for future applications such as FELs. The main purpose of this study is to generate suitable beam for the applications which requires high density of 1 nC/bunch, short pulse of 10 ps and low emittance of 1 πmm·mrad.

To design system parameters, such as rf cavity shape, rf phase, rf power, shape of laser spot, magnetic field distribution of focusing system, treatments of inside cavity and so on, we separated this study into two phases. In the first phase, a prototype single cell rf cavity and a simple beam line were manufactured. Also, a simulation code for this simple apparatus was developed. Then we try to make an agreement between experiments and simulations. In the second phase, more practical cavity and beam line will be designed to get lower emittance using this code, then a test linac will be constructed. Now, we are at the end of the first phase.

2 PRESENT STATUS OF APPARATUS

The experimental apparatus[1] is shown in Fig. 1. The single cell cavity is made of copper and bottom side of the cavity, which is also copper, is used as a cathode. The apparatus consists of two solenoid coils to focus beam, two pair of horizontal and vertical slits, a bending magnet for analyzing beam energy and a Faraday-cup. Emittance are measured using two silts and the Faraday-cup.

Laser, which type of Nd/YLF, wave length of 262 nm (fourth harmonics wave is used) and pulse width of 10 ps, is derived along laser path shown in Fig. 1.

Four types of cavities, which treatment of cavity wall is different, are manufactured for studying high power test. Fig. 2 shows the Fowler-Nordheim plot for four different cavities. Amount of dark current generated by a pure water rinsed cavity is the lowest. Maximum electric field gradient of the cathode surface was achieved up to 140 MV/m in this February using the pure water rinsed cavity.

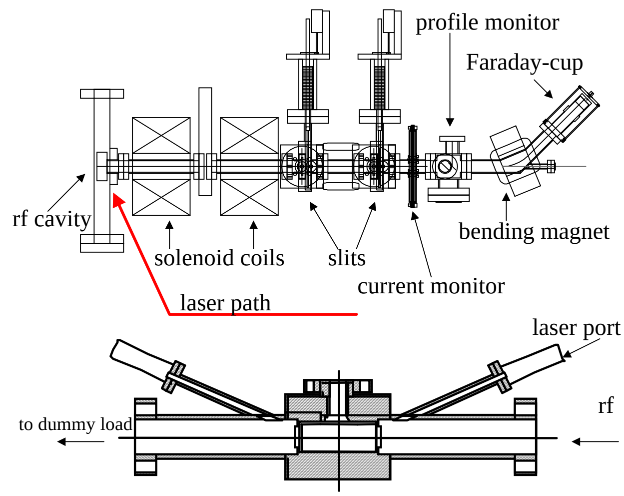

Figure 1: Outline of experiment apparatus

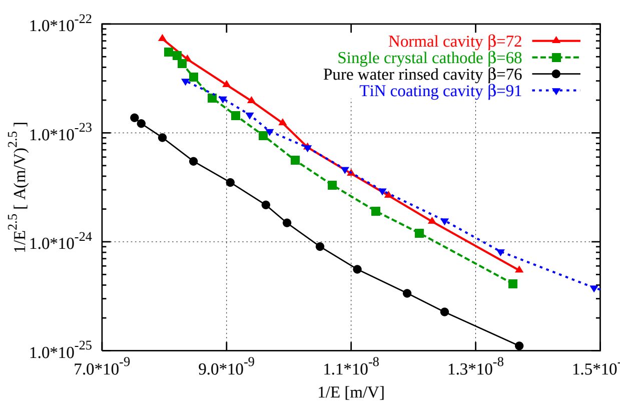

Figure 2: Fowler-Nordheim plot for four types of cavities

3 COMPARISON RESULTS

3.1 *Simulation Code*

To compare the results of experiments and simulation, the simulation code must be able to deal with practical electro-magnetic field. Our developed code[2] is three-dimensional tracking code and be able to include three dimensional fields. In this code, all actions between each electron are calculated to solve space charge effect, therefore it spends much time but high accuracy is expected.

3.2 *Initial RF Phase*

Figure 3 shows beam energy depends on an initial RF phase. The initial RF phase ϕ is defined by

$$E_{cathode} = E_0 cos(\omega t - \phi) \quad (1)$$

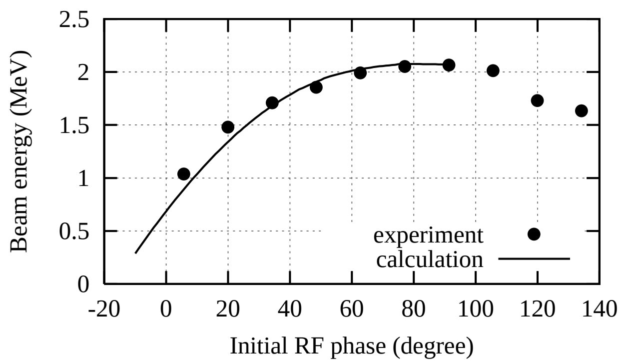

Figure 3: Beam energy dependence on initial RF phase

where, E_0 is maximum electric field on the cathode surface, ω is RF angular frequency of $2\pi \times 2856$ MHz and electron at head of bunch is generated at the time $t = 0$.

Absolute value of the initial RF phase is very important for comparing simulation with experiment. However, we can only observe relative RF phase experimentally. As comparing measured beam energy with calculated value shown in Fig. 3, absolute RF phase is obtained.

3.3 Emittance Calculation

Figure 4 shows typical calculated two dimensional normalized emittance along a beam line. In the experiment, the emittance is measured at point A, downstream of the solenoid coils. But 2D-emittance is varied in the solenoid coils as shown in Fig. 4, because there is coupling between variable x and y in the equation of motion. Therefore it is important to calculate emittance include solenoid coils for emittance comparison.

2D emittance in the simulation is defined by

$$\epsilon_x = \gamma\beta\sqrt{< x >< x' > - < x \cdot x' >^2} \qquad (2)$$

Also, measured emittance is 1σ value.

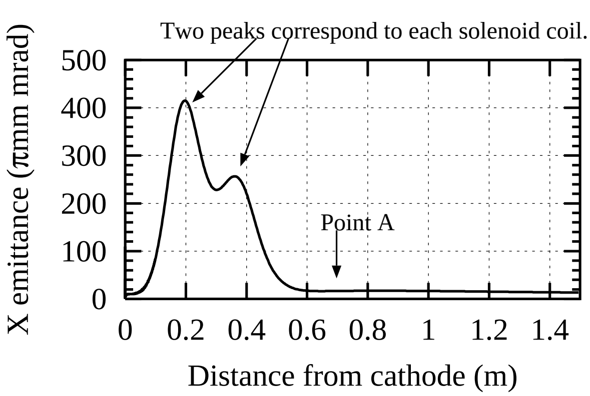

Figure 4: Typical calculated emittance along a beam line

3.4 Comparison

The comparison results are shown in Fig. 5. Parameters for experiment and simulation are shown in Table 1. Initial transverse laser beam size and beam shape could not be measured preciously in the experiment. For the simulation, we assume the transverse shape to be Gaussian distribution and three cases, that initial laser beam radius (1σ value) are different as shown in Fig. 5, are calculated.

Minimum measured emittance value and dependence on RF phase are agreed with these of simulation when initial beam radius is 0.75 mm. This value of 17 πmm·mrad is the smallest value that has been measured in our apparatus. The RF phase was 60 degrees when minimum value was obtained.

In the Fig. 5, emittance curve for experiment and for simulation slightly shifts each other. This is caused by accuracy for determination of absolute RF phase in the Fig. 3. If we shift the experimental curve 5 degrees to the right, two curves are agreed well.

In the experiment, measured beam current is reduced in the left side of Fig. 5. However in the simulation, this phenomenon is neglected because the beam current at the exit of the RF cavity can not be measured experimentally. This is a reason for disagreement in this region.

Table 1: Parameters for experiment and simulation

Maximum field gradient on the cathode	90 MV/m
Initial bunch length	10 ps
Achieved electron beam energy	2.1 MeV
Charge per bunch	0.8 nC
First solenoid coil	1100 Gauss
Second solenoid coil	520 Gauss

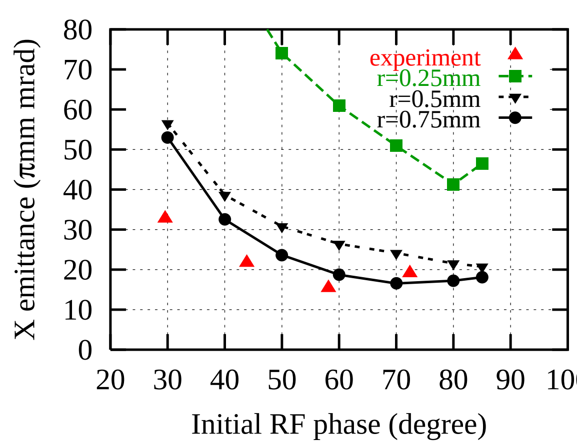

Figure 5: Emittance comparison between experiment and simulation

4 DISCUSSION FOR GETTING LOWER EMITTANCE

Parameter survey for getting lower emittance is performed using this code. Fig. 6 shows dependence of emittance, energy spread and beam bunch length on the initial RF phase, at 1.5 m from the cathode surface.

If the phase value is small, the emittance becomes larger, since energy spread of the beam becomes larger. The initial bunch length is 10 ps and corresponds to about 10 degrees. Therefore, from Fig 3, electron energy difference between head and tail of bunch grows larger in this region. This means electron velocity at head of bunch become faster than at tail of bunch. Therefore in this case, bunch length grows longer.

On the other hand, the emittance becomes smaller as the phase value is larger. However 90 MV/m curve, which is almost the same condition of Fig. 5, rebounds at 70 degrees. In this region, bunch length becomes short compared with before case, and charge density grows large. Therefore the emittance grows due to large space charge effect.

At present, the maximum cathode field achieved up to 140 MV/m as already mentioned. we also show high field gradient calculations with initial bunch length of 10 ps and 20 ps in the Fig 6.

In these calculations, to reduce space charge effect, initial transverse beam shape is assumed to be Gaussian distribution with radius of 20.0 mm (1σ), and only electrons of $r \leqq 1.0$ mm are selected for particle tracking.

Because of low electron density and high field gradient in the cavity, the value of emittance is reduced. In the calculation for 10 ps, 7.3 πmm·mrad is obtained with the phase of 80 degrees. But also the curve rebounds at 80 degrees.

In the 20 ps case, the space charge effect reduces furthermore. Therefore this curve does not rebound even if the phase is nearby 90 degrees. Moreover, even the initial bunch length is 20 ps, obtained bunch length becomes 2.6 mm (1σ value) with the phase of 85degree. This length is almost the same as 10 ps case, and much shorter than 90 MV/m case.

In this conditions, emittance value of around 6 πmm·mrad with charge of 0.8 nC/bunch will be expected in our apparatus.

5 CONCLUSION AND DISCUSSION

As the first phase of our study, the RF gun experimental apparatus and the simulation code were developed to generate high density, short pulse, low emittance beam. The minimum 2D normalized emittance of 17 πmm·mrad is obtained experimentally. This value and dependence on the initial RF phase are almost agreed with simulation results. Therefore we consider that this code is able to be used to design our second phase system.

The measured value of 17 πmm·mrad is not low enough. However in the simulation, approximately 6 πmm·mrad is expected with higher field gradient and longer initial bunch length. Now we can not perform experiment with these conditions because of unstable laser power and limitation of laser pulse length, but this experiment will be able to performed in this autumn with new laser.

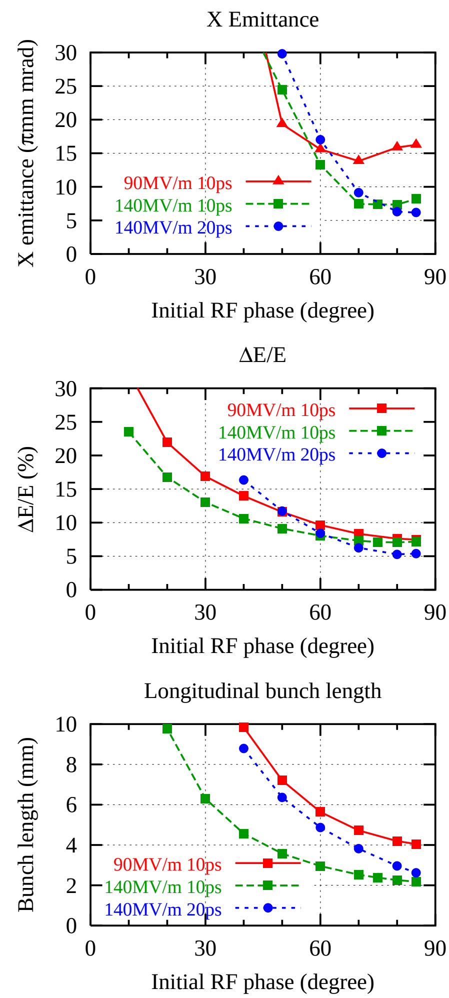

Figure 6: Calculated dependence of emittance, energy spread and bunch length on initial RF phase

By the way, as shown in eq. 1, if the initial RF phase is 90 degrees, field gradient in the cavity is zero when an electron generated. In this case, low energy electrons feel large space charge forces and the emittance grow larger. Therefore it is not ideal that the emittance becomes minimum with the phase of 90 degrees, like our cavity.

To get minimum emittance when the phase value is smaller, we must newly design cavity structure. We are going to manufacture this cavity and get more smaller emittance in the second phase.

REFERENCES

[1] T. Taniuchi et al., “Initial Results of RF gun experiment”, PAC’99, p.2015, New York, April 1999.

[2] A. Mizuno st al., “Simulation for an RF gun test apparatus in the SPring-8 Linac”, PAC’99, p.2749, New York, April 1999.