CHARACTARIZATION OF ELECTRON BEAM FROM A Mg PHOTO-CATHODE RF GUN SYSTEM *

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Abstract

Characterization of a photo-electron beam generated from a magnesium photo-cathode rf gun system at Waseda University has been developed. The vertical emittance of the electron beam was measured using slit scan technique. As a result, the vertical emittance was measured to vary from 9 mm mrad to 15 mm mrad at the bunch charge of 0.75 nC as the solenoid current changing from 97 A to 110 A. The measurements of the vertical emittance as a function of solenoid current are in good agreement with simulation results using PARMELA. On the other hand, in order to evaluate the rms bunch length monitor using beam spectrum analysis technique to apply to measuring the rms bunch length of the photo-electron beam generated from the magnesium cathode rf gun system, we have carried out the preliminary experiment using a Copper photo-cathode rf gun system and a 3m-long S-band accelerating structure at KEK-ATF injector. The availability of the rms bunch length monitor using the beam spectrum analysis technique was evaluated well by comparing with the data obtained by streak camera. As a result, the rms bunch length monitor is very useful as the non-destructive and conventional method.

1 INTRODUCTION

Laser-driven photo-cathode rf gun system can generate the low emittance and short pulse electron beam[1]. It will be applied for a compact soft X-ray source and pulse radiolysis experiments. So far, numerical simulation studies for BNL type photo cathode rf gun has performed using MAGIC and PARMELA [2-3]. Particularly, the magnesium photo-cathode rf gun system can generate the high charge electron beam up to 2 nC/bunch with energy of up to 5 MeV. It is very difficult to measure the beam emittance and the bunch length of such a low energy electron beam. Therefore, We have developed the charactarization of a photo-electron beam generated from an rf gun system[4].

2 EMITTANCE MEASUREMENT

2.1 Experimental Setup

The vertical emittance of the photo-electron beam was measured using the slit scan technique. The tungsten slit is located at 90.5 cm down stream of the beam line from the cathode. This slit is made of 1mm-thick tungsten and the slit width is 200 μm. The slit can be moved in the step of 200 μm. The beam is sliced by the tungsten slit and the image of the sliced is produced at a phosphor screen that is located at 51cm down stream from the slit. This phosphor screen is the square of 10mm and 1mm-thickness. The sliced beam image is captured by an analogue CCD camera. The captured image is digitized and stored at 320 x 240 pixels in a grayscale (8bit 256 shades of gray) using a graphic capture board on PC. In order to obtain all images of the sliced beam in each vertical positions of the slit, the slit is scanned in 200 μm step from the lower edge to the upper edge of the beam in the vertical direction. One background image is taken along with all image of the sliced beam. After background subtraction, each of the images is projected onto the vertical axis and transformed into a momentum distribution image of the sliced beam on the slit using the transfer matrix

$$\begin{pmatrix} x_n \\ x_n' \end{pmatrix} = \begin{pmatrix} 1 & L \\ 0 & 1 \end{pmatrix} \begin{pmatrix} x_{n0} \\ x_{n0}' \end{pmatrix} \quad (1)$$

and the equation

$$\Delta x_0' = \frac{\Delta x}{L} \quad (2).$$

Here n is the number of electrons, L is the distance between the slit and the screen, x_{n0} is an electron position at the slit, x_{n0}' is an electron momentum at the slit, x_n is an electron position at the screen, x_n' is an electron momentum at the screen, Δx is a beam profile spread at the screen, Δx′ is a beam momentum spread at the slit. All momentum distribution images of the sliced beam are combined and a phase space distribution of the beam on the slit can be reconstructed using the software of the computer graphics, MATHCAD. The vertical rms emittance is calculated from the phase space distribution.

2.2 Experimental results

The vertical emittance measurements using the slit scan technique were performed as the solenoid current changing from 97 A to 110 A. 100 A of the solenoid current is correspond to 1500 Gauss of the longitudinal magnetic field. Fig. 1 shows the rms normalized emittance as a function of the solenoid current. As a results, the minimum rms normalized emittance was measured at 107.5 A of the solenoid current. The minimum rms normalized emittance value was 9.02 mm

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mrad. Other experimental in this experiment are shown in table 1.

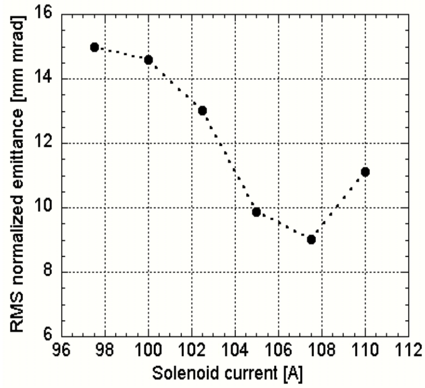

Fig. 1: The rms normalized emittance vs the solenoid current (results of the measurements)

Table 1: Experimental parameters

Laser Injection Phase	55 degree
Laser spot size	2mmϕ (FWHM)
Bunch Charge	0.8 nC/bunch
Beam Energy	4 MeV

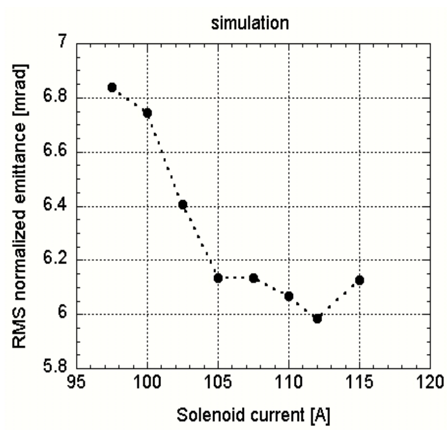

Fig. 2: The rms normalized emittance vs the solenoid current (results of the simulations)

We have carried out the numerical simulation using PARMELA to evaluate these results of the emittance measurements using the slit scan technique. Fig. 2 shows results of the simulations for the rms normalized emittance as a function of the solenoid current, which is changed from 97.5 A to 115 A. When the results of the simulations are compared with the results of the measurements, both of the tendencies on the rms normalized emittance change agreed with the solenoid current. A little difference about absolute values between the simulation results and the measurement results may be caused by the definition of the initial emittance in the simulation. Though the defined initial emittance is 0 in the simulation, it is not 0 in the experiment. Fig.3 upper shows the typical emittance distribution images on 97.5 A, 100 A, 107.5 A of the solenoid current in these experiments. Fig.3 lower shows the typical emittance distribution on 97.5 A, 100 A, 110 A of the solenoid current in these simulations. These figures show that the shapes of the emittance distribution images agree with the shapes of the emittance distribution in the simulation.

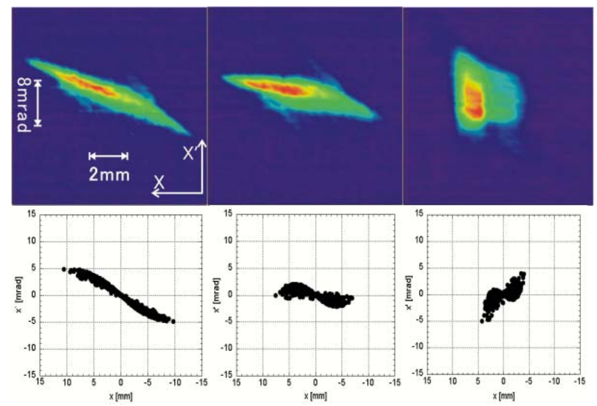

Fig.3: The typical phase space images (Upper figures are the results of the measurements Lower figures are the results of the simulations)

3 BUNCH LENGTH MEASUREMENT

The bunch length is generally measured using Streak camera method. In this method a high intensity radiation, such as OTR and Cherenkov radiation, induced by electron beam is essential. Energy of the electron beam generated from the rf gun is not enough to generate the high intensity radiation. The measurement method of the rms bunch length using the electron beam spectrum analysis technique has been developed[5]. In order to apply this method to measuring the rms bunch length generated from the magnesium photo-cathode rf gun system at Waseda University, the preliminary experiment of this method using a Copper photo-cathode rf gun system and a 3m-long S-band accelerating structure at KEK-ATF injector have been demonstrated.

3.1 Principle

The bunch length can be obtained from the frequency spectrum of a bunch. When the normalized frequency ωσ is less than 1, an amplitude ratio of two frequency components in the beam spectrum gives the rms bunch length σ from the equation

$$\sigma = \sqrt{\frac{2}{\Delta\omega^2}\ln\left\{\frac{|F_1(\omega_1)|}{|F_2(\omega_2)|}\right\}} \quad (3).$$

Here ω_1 and ω_2 are the detected two frequencies ($\omega_2 > \omega_1$), $|F_1(\omega_1)|$ and $|F_2(\omega_2)|$ are amplitude of the spectrum, and $\Delta\omega^2=\omega_2^2-\omega_1^2$. This is the same equation for a Gaussian distribution. Hence, we can obtain the rms bunch length by measuring the attenuation coefficient in the spectrum.

3.2 Experimental Setup & results

Table 2: Experimental parameters

Laser spot size	2mmϕ (FWHM)
Bunch Charge	0.8 nC/bunch
Beam Energy	50 MeV

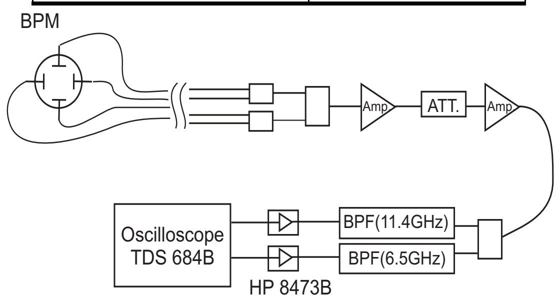

Fig. 4: Set up of the rms bunch length monitor

Laser photo cathode rf gun generates the electron beam by irradiating UV laser light (262 nm, 4th harmonics of Nd:YLF laser light). The bunch length of the electron beam primarily depends on the laser pulse width. The UV laser has ~10 ps pulse width (FWHM). Other parameters in this experiment are shown in table 2. The measurement components such as the beam position monitor, the attenuators, the amplifiers and the detectors are shown in Fig.4. The signals of the electron beam are picked up through the button typed beam position monitor. These signals are combined by the combiner. The combined signals are divided into two signals to extract two frequency components using band-pass filters.

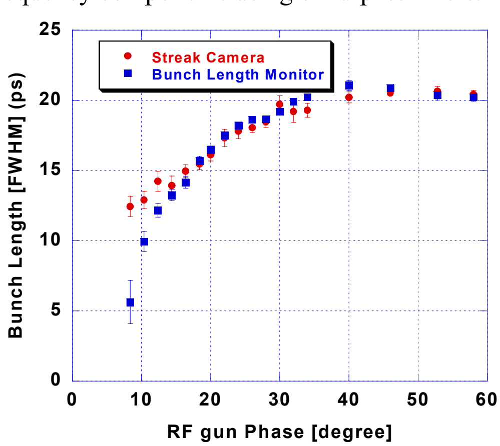

Fig. 5: The bunch length as a function of the rf gun phase (laser injection phase)
(Circle-points are results of the streak camera method, Square-points are results of the bunch length monitor)

In this experiment, the 6.4 GHz and 11.3 GHz band-pass filters (BPF) were chosen to detect the two different frequency spectra. The frequency characteristics of these BPF were measured using the Network Analyser. Both of the filters have the same bandwidth (~1GHz). The amplitude of the detected spectrum was observed using the real time sampling oscilloscope (TDS 684B). The rms bunch length is derived from eq. (3) using the amplitude of the spectrum. The rms bunch length was measured using both the rms bunch length monitor and the streak camera method as the function of rf phase (laser injection phase). Fig.5 shows the results of the bunch length measurements that are normalized to FWHM value and indicates that the tendency of the results using the rms bunch length monitor corresponds with the results using the streak camera method, and moreover, the absolute values of the measured bunch length using the rms bunch length monitor agrees with that of streak camera method.

4 CONCLUSION

The vertical emittance of the photo-electron beam generated form the magnesium photo-cathode rf gun at Waseda University was measured to vary from 9 mm mrad to 15 mm mrad at the bunch charge of 0.75 nC as the solenoid current is changed from 97 A to 110 A. The minimum rms normalized emittance value was 9.02 mm mrad at 107.5 A of the solenoid current.

The rms bunch length monitor using the beam spectrum analysis technique has been evaluated in this preliminary experiment at KEK-ATF. So we will apply the rms bunch length monitor to measuring the photo-electron beam generated from the magnesium cathode rf gun system at Waseda University.

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