BEAM DIAGNOSTICS FOR A PHOTOCATHODE RF-GUN SYSTEM*

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Abstract

Beam diagnostic systems for high quality electron beam emitted from photo-cathode rf gun have been developed. Beam characteristics such as bunch length and emittance measurements were performed at Waseda University. The bunch length was measured using an rms bunch length monitor based on beam spectrum analysis. The monitor is very useful as the non-destructive and conventional tool even for the relatively low energy electron beam around 5MeV. The measurement results of the rms bunch lengths using this monitor are in good agreement with the simulation results of PARMELA. However, it is not applicable for the measurement of longitudinal profile of the electron bunch, so that we have started the manufacturing of a deflection cavity, so-called RF-Kicker, to measure the longitudinal profiles of the bunch. The emittance has been measured by using a slit scan technique. By using double slit scan technique, emittance of 9mm mrad has been obtained. Though the value is not satisfactory small, we believe that much smaller emittance can be obtained by optimizing a laser profile. The measurement results and progress of rf gun at Waseda University will be presented at the conference.

1 INTRODUCTION

Laser-driven photocathode rf-gun system can generate the low emittance and short pulse electron beam. Recently photocathode rf-gun system is applied as an electron source for FEL and other applications. [1] Numerical simulation studies and experiments for photocathode rf-gun have been performed. [2] At Waseda University, a low emittance electron beam is generated by BNL type 1.6 cells S-band photocathode rf-gun, which has advantages such as time structure of electron beam can be controlled by characteristics of laser light, a bunching system is not necessary, and high accelerating field in the cavity of rf-gun can be suppress emittance growth due to space charge effect. The electron beam is used for the pulsed X-ray generation by using laser Compton scattering for a biological investigation and the pulse radiolysis experiments for the observation of ultra-fast phenomena. [3] For these applications, beam diagnostics for photocathode rf-gun is very important. Our system can generate a high charge electron beam up to 2nC/bunch with energy of up to 5MeV. [4] It is very difficult to measure the emittance and the bunch length for such a low energy electron beam. For the bunch with such a low energy, space charge effect isn't negligible in the measurements. Furthermore, the signal from the beam such as some kind of radiation, is so small that it's difficult to use them for the measurements. Therefore, we have developed the characterization techniques of a photo-electron beam generated from an rf-gun system. These techniques are suitable for the bunched electron beam with relatively low energy. We have studied non-destructive bunch length monitor and longitudinal profile monitor for the measurements of bunched electron beam with relatively low energy. On the other hand, we have also studied the precise emittance measurement technique using slit scan technique to optimise the injected parameters for minimum emittance. In this paper, we will present the results for bunch length measurements and studies for optimum parameters of injected laser to reduce emittance.

2 BUNCH LENGTH MEASUREMENTS

The bunch length is often measured by using the streak camera method. In the method, high intensity radiation, OTR or Cherenkov radiation, induced by electron beam is required. Energy of the electron beam emitted from the rf-gun at Waseda University is not enough to generate an intense radiation. Hence, we have designed RMS bunch length monitor as a non-destructive monitor and started the manufacturing of deflection cavity, so-called RF-Kicker as a longitudinal profile monitor. RMS bunch length monitor is based on beam spectrum analysis. This method is useful for measuring the bunch length with low energy. Longitudinal profile monitor, RF-Kicker can deflect the bunch and the longitudinal profile is projected transverse direction. [5]

2.1 RMS Bunch Length Monitor Principle

The RMS bunch length monitor based on beam spectrum analysis is very useful as the non-destructive and conventional tool even for the relatively low energy electron beam around 5MeV. In this method, when the normalized frequency $\omega\sigma$ is less than 1, an intensity ratio of two frequency components in the beam spectrum gives the RMS bunch length (σ_z) from the equation

$$\sigma_z = \sqrt{\frac{2}{{\omega_2}^2 - {\omega_1}^2} \ln\left(\frac{|I_1(\omega_1)|}{|I_2(\omega_2)|}\right)} \quad (1)$$

Here, ω_1 and ω_2 are the detected two frequencies ($\omega_1 < \omega_2$), $|I_1(\omega_1)|$ and $|I_2(\omega_2)|$ are the intensity of the frequency spectrum at ω_1 and ω_2, respectively. Eq.(1) can adapt not only the gaussian distribution bunch, but also any other distribution bunches. [6]

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2.2 Experimental Setup

Rf-gun system at Waseda University is consist of rf-gun cavity, solenoid magnet and beam diagnostic components [4]. Beam signal for two frequencies analysis is picked up by the beam position monitor (BPM) with button shaped electrode, installed in the beam line. Four signals, which are picked up by four electrodes, are combined and divided into two signals. Two signals are extracted two frequency components around 6.4GHz and 11.4GHz by the band pass filter, respectively. After the frequency extraction, signals are detected using detector (HP8473B) and sampled by the oscilloscope (TDS684B).

In this setup, Eq.(1) can be changed Eq.(2), includes the experimental factor.

$$\sigma_z = \sqrt{\left\{23.9\sqrt{\ln\left(\alpha\frac{|V_1(6.4GHz)|}{|V_2(11.4GHz)|}\right)}\right\}^2 - \sigma_{Spread}{}^2} \quad (2)$$

Here, α is a frequency coefficient factor between the two frequencies from the BPM to the detector. V_1 and V_2 are the intensities of the beam spectrum, extracted around 6.4GHz and 11.4GHz, respectively. And σ_{Spread} is the longitudinal spread of the electric field, caused by the electron bunch. σ_{Spread} is expressed by using the radius of beam pipe R, and the Lorentz factor γ.

$$\sigma_{Spread} = R \times \frac{1}{\gamma} \quad (3)$$

2.3 Experimental Results

RMS bunch lengths as a function of the laser injection phase measured on this experimental setup are shown in Fig.1. Experimental parameters are shown in Table.1.

Table 1: Experimental Parameters

Laser Power	$52\mu J$
Laser Pulse Length	10ps (FWHM)
Solenoid Current	100A

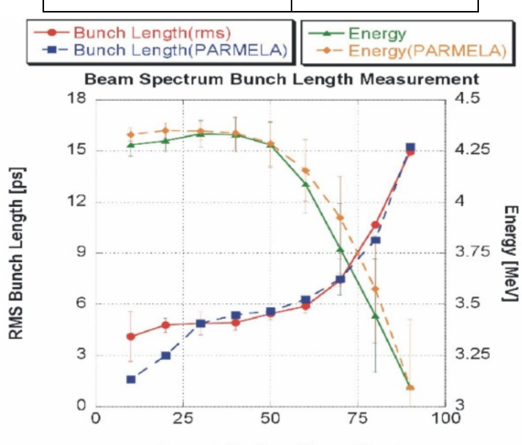

Fig.1: RMS Bunch Lengths as a function of the Laser Injection Phase

In Fig.1, the solid lines and the plots are the experimental results, and dotted lines show the simulation results of PARMELA. As shown in Fig.1, experimental results of bunch lengths measured by RMS bunch length monitor using beam spectrum analysis show good agreement with that of simulation results of PARMELA. However, when the laser injection phase is low, the experimental results are different from the simulation results. This difference depends on the decrease of the beam signal due to bunch charge and the spectrum intensity ratio due to the decrease of the bunch length.

2.4 Longitudinal Profile Monitor

Though RMS bunch length monitor using beam spectrum analysis is useful as a non-destructive monitor, experimental results that we obtain are only a value of the bunch length. Therefore, we have started the manufacturing of the deflection cavity (so-called RF-Kicker) to measure the longitudinal profiles of bunched beam. FEL requires an extreme short bunch and low emittance electron beam. RF-Kicker method is applicable not only for a longitudinal profile monitor but also for measurement an extreme short bunch length. Time resolution of the RF-Kicker method can be shorter than that of the streak camera. As shown in Fig.2, RF-Kicker is composed of deflection cavity and profile monitor, screen monitor or wire scanner.

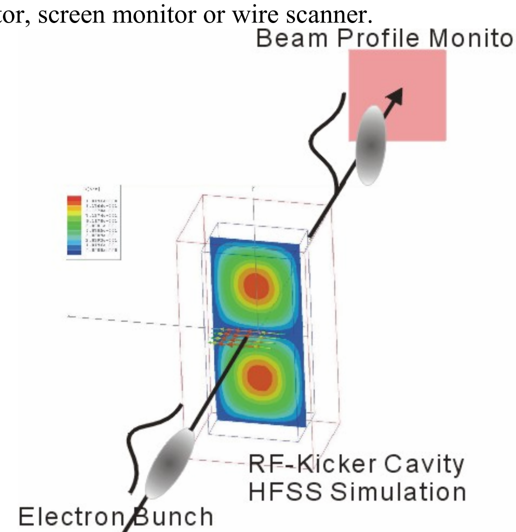

Fig.2: Schematic of RF-Kicker Longitudinal Profile Monitor

In Fig.2, RF-Kicker cavity demonstrates the simulation result using HFSS (High Frequency Structure Simulator: Ansoft). Simulation result shows electric field and magnetic field in the cavity at 2856MHz. The contour mapping shows the electric field, and arrows magnetic field. This cavity is designed to excite TM120 mode at 2856MHz. TM120 mode has the transverse magnetic field in the beam orbit (described with arrows in Fig.2). This transverse magnetic field deflects the electron bunch, and the bunch longitudinal profile can be projected the transverse direction.

3 TRANSVERSE EMITTNCE STUDIES

At Waseda University, transverse emittance is measured using slit scan technique. [7] Slit scan technique can reduce the space charge effect rather than Q-scan technique. In this measurement, we studied the effect of the injection laser power and laser spot size on the transverse emittance. The total emittance we can measure is represented as follows

$$\varepsilon = \sqrt{\varepsilon_{th}{}^2 + \varepsilon_{rf}{}^2 + \varepsilon_{SC}{}^2 + \cdots} \quad (4)$$

The emittances ε_{th}, ε_{rf} and ε_{SC} represents thermal emittance, rf effect emittance and space charge effect emittance, respectively. These are simply proportion to following parameter [8][9][10],

$$\varepsilon_{th} \propto R_0$$

$$\varepsilon_{rf} \propto \sigma_x{}^2 \sigma_z{}^2 \quad (5)$$

$$\varepsilon_{SC} \propto \frac{Q}{\sigma_z} \cdot \frac{\sigma_z}{(3\sigma_x + 5\sigma_z)}$$

Therefore, changing the injected laser power and spot size means changing the space charge effect emittance. To optimise these injected laser parameters, we can decrease the transverse emittance.

3.1 Experimental Setup

Slit scan technique is the effective method to measure the transverse emittance with low energy. This technique consists of two tungsten slits and faraday cup. The first tungsten slit is located at 955mm downstream of the beam line from the cathode, and the second slit is 225mm downstream from the first slit. The beam charge, sliced by the double slits is detected using the faraday cup. To measure the sliced charge, we can obtain the phase space distribution of the beam and the emittance.

3.2 Experimental Results

Table 2: Experimental Parameters

Laser Pulse Length	10ps (FWHM)
Bunch Length	5ps (RMS)

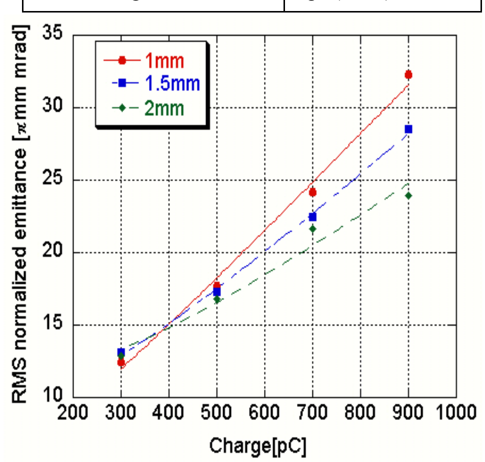

Fig.3: Transverse Emittance as a Function of the Bunch Charge and Laser Spot Size

Experimental results and parameter are shown in Fig.3 and Table.2 respectively. In Fig.3, plots show the experimental results. The linear lines fitted on the plots are given from Eq.(6).

$$\varepsilon = \sqrt{aQ^2 + \varepsilon_0{}^2} \quad (6)$$

Here, a is a factor of the space charge effect on the emittance. And ε_0 is the other effect on the emittance. The parameters of the fitted lines are shown in Table.3.

Table.3:Parameters of the Fitted Lines

Spot Size	a	ε_0
1mm	1.19×10^{-3}	6.1
1.5mm	0.87×10^{-3}	8.4
2mm	0.61×10^{-3}	11.1

As shown in Table.3, as is laser spot size gets smaller, space charge effect on the emittance is larger. On the other hand, as is laser spot size larger, other effect, such as a thermal emittance and an rf emittance are larger. It is clear that optimum parameter for the laser spot size depends on the bunch charge, determined from the laser power.

4 CONCLUSIONS

We have measured the bunch length using RMS bunch length monitor. The results of this method show good agreement with simulation results of PARMELA. Longitudinal profile monitor, RF-Kicker, is designed. The simulation of the cavity using HFSS and a cavity manufacturing have been performed. Bunch length measurements using RF-Kicker will be started in this summer.

In emittance studies, we measured the emittance as a function of the injected laser power and spot size. Optimum conditions of the injection laser parameters have been obtained.

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