MEASUREMENT OF BEAM CHARACTERISTICS FOR PHOTO-ELECTRON BEAM AT WASEDA UNIVERSITY *

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Abstract

The low emittance and short pulse electron beam is expected to be used in a wide field, such as X-ray generation by inverse Compton scattering, pulse radiolysis, etc. The laser driven photo cathode rf gun system is possible to produce the low emittance and short pulse electron beam [1]. It is very important for generating the low emittance and short pulse electron beam to measure the beam characteristics such as the bunch length precisely. In this report, the measurement system of the bunch length using frequency analysis for the photoelectron beam generated by the rf gun and results of the preliminary experiment at KEK-ATF (Accelerator Test Facility) Linac is described.

1 INTRODUCTION

The low emittance and short pulse electron beam generation system using laser driven phto cathode rf gun have been developed at Waseda University. It will be applied for a compact soft X ray source using inverse Compton scattering and pulse radiolysis experiment. So far, numerical simulation studies for BNL type photo cathode rf gun has performed using the MAGIC code and PARMERA code [2-3]. Last year, rf gun cavities have been manufactured using the diamond turning technique to reduce the dark current at KEK machine shop. Before installing rf gun in Waseda University we have carried out the preliminary experiment at KEK-ATF Linac to confirm the availability of rf gun and to develop the measurement method of the beam characteristics before installing rf gun in Waseda University. One of the most important beam characteristics is the bunch length. However, the general bunch length measurement technique using Streak Camera can not be applied to a few MeV electron beam because we can not obtain the enough light for the Streak Camera related the electron beam. Therefore we are developing a new method for the bunch length measurement using the beam spectrum analysis.

2 EXPERIMENTAL SETUP

As an experimental preparation, rf processing of rf gun cavities has been performed for one month. In the beam experiment, 3 MW rf power was fed to the rf gun and we expected maximum accelerating field on the axis of rf gun cavity was about 60 MeV/m. the experimental setup shown in fig.1. rf gun system with solenoid magnet for emittance compensation was installed. Many diagnostics tools, which are a faraday cup, beam profile monitors, a movable tungsten slit for measurement of beam emittance, a button type beam position monitor (BPM), were also set into beam line to measure the beam characteristics.

The button type BPM was used to pick up the beam spectrum. The bunch length was derived from this beam spectrum using frequency analysis tequnique.

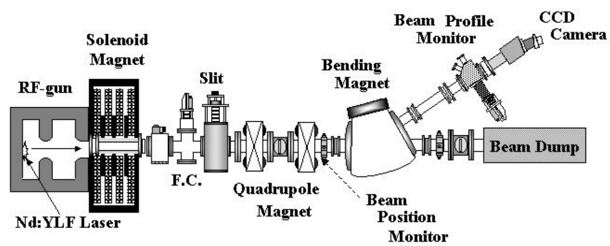

Fig. 1 : Beam Line Setup in the preliminary experiment at KEK-ATF

3 BEAM CHACTARISTICS MEASUREMENT

Bunch charge was measured using a faraday cup. Fig.2 show the beam intensity with different injection rf phase of the laser. As a result, the maximum charge of the electron beam was about 4.2 mV on the oscilloscope which correspond to ~300 pC/bunch.

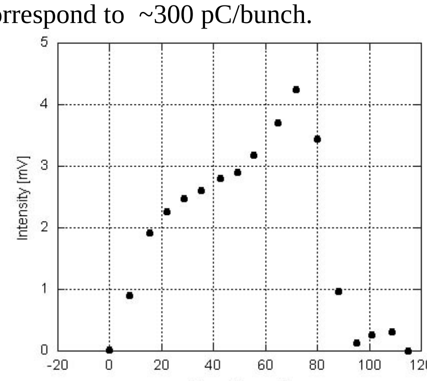

Fig. 2 : Beam Intensity vs injection rf phase

Maximum Energy was about 2.7 MeV. It was measured using an analyzer magnet. Minimum normalized emittance is about 16 mm mrad using the slit

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scan method. Concerning Slit scan method we have measured beam intensity on the down stream profile monitor changing the up stream movable tungsten slit (the slit width is about 150 μm) every 100 μm with the stepping mortar and the magnescale (Sony, LY105A).

We have carried out the measurement of the rms bunch length using the beam position monitor.

4 RMS BUNCH LENGTH MONITOR

4.1 Principle

The bunch length is an important parameter to generate high quality electron beam and short X-ray pulsed using inverse Compton scattering. In the ordinary way the bunch length is measured using Streak camera. In this method the high intensity radiation related electron beam is needed, such as OTR and Cherenkov radiation, and so on. But Energy of electron beam generated from rf gun is not so high that we can't generate high intensity radiation.

Therefore we have developed the measurement of the rms bunch length using the electron beam spectrum analysis technique [4]. The bunch length can be obtained from the frequency spectrum of a bunch. When the normalized frequency •σ is less than 1, an amplitude ratio of two frequency components in the beam spectrum gives the rms bunch length σ from Eq.(1) by

$$\sigma = \sqrt{\frac{2}{\Delta\omega^2}\ln\left\{\frac{|F_1(\omega_1)|}{|F_2(\omega_2)|}\right\}} \quad (1).$$

Here, $\bullet_1$ and $\bullet_2$ are the detected two frequencies ($\bullet_{2>}\bullet_1$), $|F_1(\bullet_1)|$ and $|F_2(\bullet_2)|$ are amplitude of the spectrum, and $\Delta\bullet^2=\bullet_2^2-\bullet_1^2$. 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.

4.2 Results and discussion

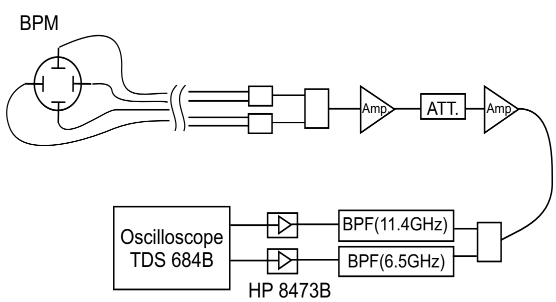


Fig. 3 : RMS Bunch Length Measurement Setup

Laser photo cathode rf gun generates the electron beam by irradiating UV laser light (262nm,4th harmonics of ND:YLF laser light). The bunch length of the electron beam basically depends on the laser pulse width. In this experiment the pulse width of UV laser light was ~10ps (FWHM). The bunch length can be controlled changing the laser injection phase to the rf gun. Fig. 3 shows the rms bunch length measurement setup. It was consisted of the signal combiner, attenuators, rf amplifiers, rf detectors, and band-pass filters for two different frequencies. Beam signals were picked up from the button type beam position monitor and these signals were combined by the Power Combiner to neglect the beam orbit dependence. The combined signals were divided into two signals to extract two different frequency components using band-pass filters.

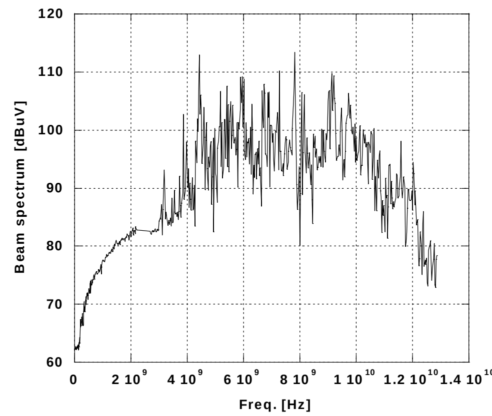


Fig. 4 : Frequency Characteristics of BPM

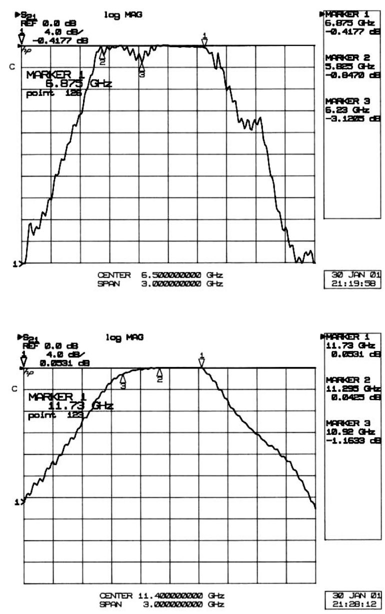
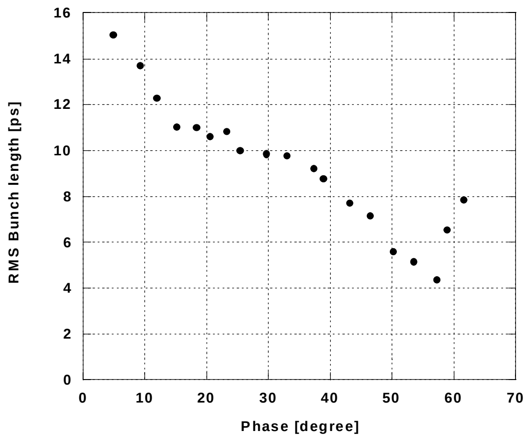


Fig. 5 : Band width of the band-pass filters : the upper figure is 6.4 GHz; the lower figure is 11.3 GHz.

In this experiment we have prepared 3 band-pass filters, 2.8 GHz, 6.4 GHz and 11.3 GHz, for the measurement. However, the frequency range of the 2.8 GHz filters includes fundamental rf frequency (2856 MHz) and the signals should be noisy due to the dark current. The frequency characteristic of the BPM electrodes using the beam signals is shown in fig.4. Fig. 4 indicated that the range of the signal, which is lower than about 3 GHz, don't pass through the electrodes of BPM. Therefore the detected frequencies should be larger than about 3 GHz. Thus 6.4 GHz and 11.3 GHz BPF were chosen to detect the two different frequency spectra. The frequency characteristics of these BPF were measured using Network Analyzer and the results of measurement are shown in fig. 5. We found out that 6.4 GHz band-pass filter and 11.4 GHz band-pass filter have the same bandwidth (~1GHz). The amplitude of detected spectrum by HP 8473B was observed using the real time sampling oscilloscope (TDS 684B). The rms bunch length was derived from eq. (1) and these amplitudes. Additionally attenuation coefficient of the cables (RG 223/u) was proportional to the square rout of the frequency.

The rms bunch length was measured by changing rf phase and the results are shown in fig. 6. We can obtain the rms bunch length less than 5 ps.



.Fig. 6 : RMS Bunch Length vs rf phase for rf gun

4.3 Evaluation of RMS Bunch Length Monitor

We have evaluated the availability of the rms bunch length monitor using the beam spectrum analysis technique by comparing with the Streak Camera method. The 80MeV electron beam generated from the thermionic injector consists of a thermionic electron gun, two sub-harmonic gun system in KEK-ATF injector linac was used. The bunchers (SHB), S-band buncher and a 3m-long S-band accelerating structure (L0).

The L0 accelerating phase was varied to change the bunch length of an electron beam. We applied to measure the bunch length using the rms bunch length monitor and Streak Camera method. Fig. 7 shows the results of the bunch length measurement as a function of L0 phase. In this measurement a flactuation of the bunch length was a few ps and it should came from the SHB phase instability.

Fig.7 indicate that the tendency of the rms bunch length monitor agrees with Streak Camera method. However, the absolute values of the measured bunch length have a little difference between the results of the rms bunch length monitor and Streak Camera method. This difference was caused by the attenuation coefficient error. By measuring the attenuation coefficient more accurately, the absolute values of the measured bunch length expect to correspond each other. So we can obtain the availability of the rms bunch length monitor.

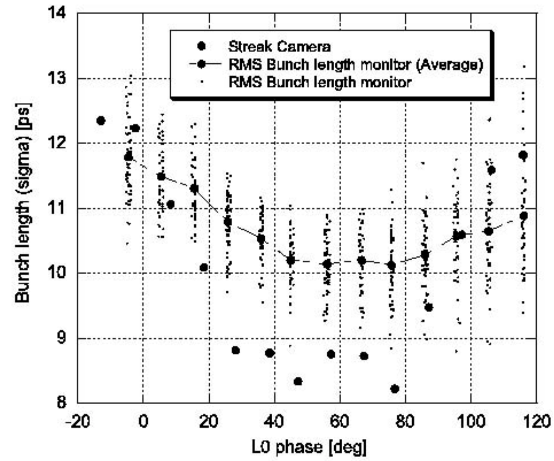


Fig. 7 : RMS Bunch Length vs L0 rf Phase for the linac section with Streak Camera (average for 5 shots) and RMS Bunch length monitor using the beam spectrum analysis (30 shots and average)

5 CONCLUSION

We have developed and demonstrated the measurement method of the rms bunch length of electron beam, in this preliminary experiment at KEK-ATF. In this method, two frequencies of the beam spectrum are applied for the calculation of bunch length. As the results, we have succeeded to measure the rms bunch lengths less than 5 ps, and confirmed the availability of the rms bunch length monitor.

At present we have installed rf gun at Waseda University. We are now in the preliminary stage of operation, and the rf aging is undergoing up to 6 MW.. Temporal goal of electric field in the rf cavity is 100MV/m, and this value means that we can obtain about 5 MeV electron beam at Waseda University.

6 REFERENCES

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