MULTI-BUNCH ELECTRON BEAM GENERATION BASED ON CS-TE PHOTOCATHODE RF-GUN AT WASEDA UNIVERSITY*

Y.Yokoyama†, T.Aoki, K.Sakaue, T.Suzuki, J.Yokose, M.Washio, RISE, Tokyo, Japan
J.Urakawa, N.Terunuma, H.Hayano, KEK, Ibaraki,Japan
S.Kashiwagi, ISIR, Osaka, Japan‡
R.Kuroda, AIST, Ibaraki, Japan

Abstract

At Waseda University, we have been studying a high quality electron beam generation and its application experiments with Cs-Te photocathode RF-Gun. We have already succeeded in generating a stable high-charged single-bunch electron beam. To generate more intense electron beam, we designed a multi-bunch electron linac and developed the multi-pulse UV laser which irradiates to the cathode. The target values of the number of electron bunch and bunch charges are 100bunches/train and 800pC/bunch, respectively. In addition, we adopted the method of the amplitude modulation of the incident RF pulse to the S-band klystron in order to compensate the energy difference in each bunch because of the slow rise time of acceleration voltage in cavity and beam loading effect in the accelerating structure.

INTRODUCTION

A photocathode RF-Gun is regarded as one of the best electron injector sources and has been developed around the world because the high quality electron beam i.e. high-intensity, short-pulse, and low-emittance, can be produced. We have been developing a table-top size high quality electron source based on photocathode RF-Gun and performing its application experiments, such as pulse radiolysis experiment[1] and soft X-ray generation using laser-Compton scattering[2], at Waseda University. We have already succeeded in stable generating a single-bunch electron beam to have higher charge and energy by improving the RF-Gun cavity with a Cs-Te cathode, which has higher quantum efficiency than Cu cathode used before.[3] However, in the soft X-ray generation which is one of application experiments, X-ray yield of our system wasn't enough to be applied for the soft X-ray microscope. Therefore, we have been planning a multi-pulse laser-Compton scattering system in order to enhance the luminous intensity of the X-ray. We need to make both multi-bunch electron beam and multi-pulse collision laser for this purpose, and at first we have been concentrating for developing the multi-pulse UV laser system to generate the multi-bunch electron beam.

Further, in case of the multi-bunch electron linac, bunch-by-bunch energy difference will be caused by the slow rise time of accelerating voltage in the RF cavity and beam loading effect in the accelerating structure.[4] To compensate the energy difference, we adopted the method making the flat energy distribution of the accelerating voltage by modulating amplitude of input RF pulse to the klystron system, called ΔA Method.[5] In this conference, we will report design properties of our multi-bunch electron linac, the results of the multi-bunch electron beam diagnosis and the energy difference compensation using ΔA method.

* Work supported by JSPS Grant-in-Aid for Scientific Research (B) (2) 16340079 and a Quantum Beam Technology Program of JST

† trp-gill@asagi.waseda.jp
‡ The present address: LNS, Tohoku University, Miyagi, Japan

MULTI-PULSE UV LASER SYSTEM

In our system, 119MHz IR laser generated from Nd:YLF mode-locked laser, called Pulrise-V. The system consists of the three parts: pulse train picker part, amplification part, and frequency conversion part. The schematic view of our multi-pulse laser system is shown in Fig.1.

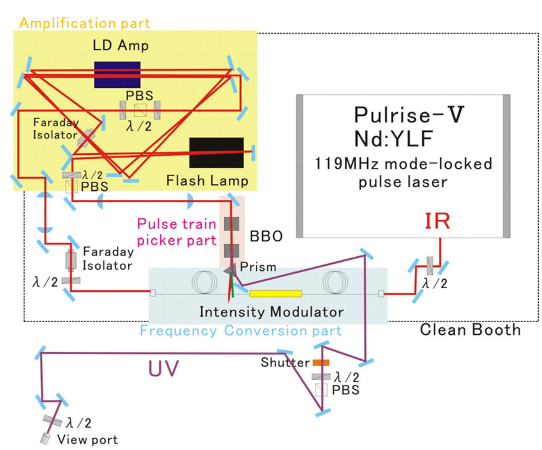

Figure 1: The Schematic view of Multi-Pulse Laser System.

Pulse Train Picker Part

The mode-locked pulse laser is injected into the fiber because we newly installed a LN intensity modulator for the pulse train pick instead of a pockels cell. Optical alignment of fiber injection is more difficult than the pockels cell, but it is effective in cutting off voltage of 5V which is 1/640 of pockels cell. Therefore, single-pulse pick was also enabled, though the pockels cell was difficult using commercial power supply.

Amplification Part

We installed the two systems, the LD pumped amplifier 3-pass system and the FL(Flash Lamp) pumped amplifier 2-pass system, because we could not obtain enough gain to generate UV laser in the preliminary experiments using only LD pumped amplifier.[6] We made it using triangle laser pass for LD 3-pass amplification and installation of isolator between LD pumped amplifier and FL pumped amplifier to prevent the self-resonance. As a result, though the intensity of IR laser was 8.4pJ/pulse before the amplification, it was 1.26μJ/pulse after LD 3-pass amplification and was 25.2μJ/pulse after FL 2-pass amplification So the gains of 1.5×10^5 and 20 was obtained, respectively.

Frequency Conversion Part

1047nm IR laser was converted to 523.5nm Green laser and Green laser was converted to 262nm UV laser based on SHG(Second Harmonic Generation) and FHG(Fourth Harmonic Generation) by using two nonlinear crystals. After the conversion, we used a prism to separate FHG light from fundamental. Actual intensity of UV laser, however, was 0.25μJ/pulse; total transformation efficiency is 1% due to the alignment and/or nonlinear crystal optimization.

ΔA METHOD

Principle

One of the problems due to multi-bunch electron linac is beam energy difference in the bunch train. It is caused by beam loading effect and the slow rise time of accelerating voltage. In our system, it can be considered that beam loading effect is small enough, because the charge per bunch is low and bunch interval is long. However, we must use the transitional voltage when the rectangular RF pulse, shown in Fig.2 in blue line, applied into the RF-Gun. Because filling time of the cavity is relatively long and the width of the initial RF pulse is limited 4μs by the klystron spec, we need to consider ΔA method making the flat energy distribution for accelerating voltage by modulating amplitude of input RF pulse shown in Fig.2 in red line. Expected modulation of RF pulse is represented by:

$$P(t) = \frac{P_1}{[1 - \exp\left(-t/t_f\right)]^2} \quad (1)$$

where, P_1 is RF power existing accelerating voltage at the start time of modulation and t_f is filling time of the cavity.

Setup

We newly installed an amplitude modulator in low level RF system in order to modulate RF pulse. The shape of the modulation was created by a function generator(Tektronix, AFG3021), under the consideration of the in-out properties of each devices such as the pulse modulator, the driver amplifier, and the klystron.

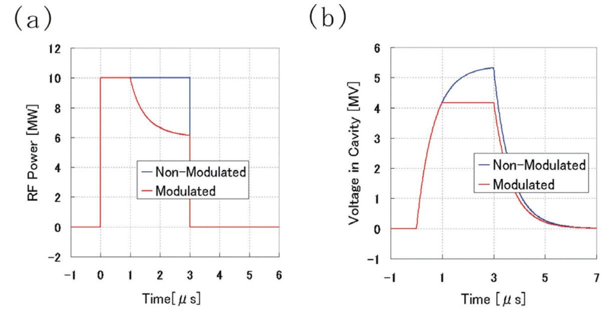

Figure 2: Calculation of (a) input RF pulse and (b) accelerating voltage in cavity. The blue lines are non-modulated RF pulse and the red lines are modulated one.

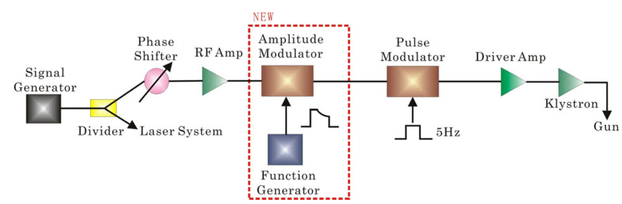

Figure 3: The Schematic view of RF System for ΔA method.

As a result, the output wave from the klystron was consistent with the expected wave shown in Fig.4(a). Also observation of voltage in cavity shown in Fig.4(b) was confirmed that it was succeeded in making the flat accelerating voltage over 2μs. The pickup signal is small compared with RF noise due to the small coupling constant between the RF pickup port and the cavity.

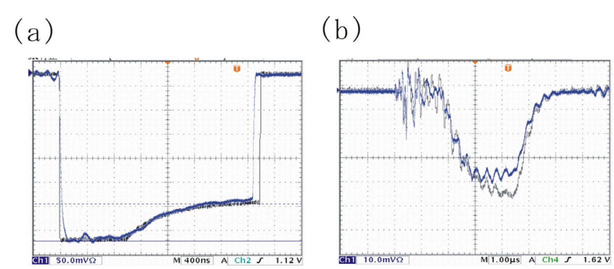

Figure 4: (a) The blue and black line are the results of observation of the output wave from the klystron and the expected waveform, respectively. (b) The blue and black line are observation of accelerating voltage in cavity when it is modulated and non-modulated, respectively.

EXPERIMENTS

Experimental Setup

Charge and energy was measured with a Faraday cup and a screen after the analyzer magnet in the old beam line layout, but it was not able to measure each bunch parameters due to their low temporal resolution. So we installed a FCT(Fast Current Transformer) and a BPM(Beam Position

Monitor) into the beam line for the multi-bunch electron beam. The new experimental setup is described in Fig.5. The new part was highlighted by color. It is nondestructively possible to measure the charge and energy.

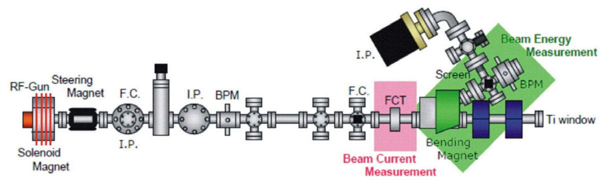

Figure 5: The Schematic design of Experimental Setup.

Charge & Energy Measurement

The results of 100 bunches multi-bunch electron beam charge and energy measurement per bunch are shown in Fig.6 and Fig.7, respectively.

Regarding the beam charge, it was measured from maximum 116.9pC/bunch to minimum 65.7pC/bunch. The bunch-by-bunch charge difference is caused by the intensity difference of UV laser. Then, the quantum efficiency of cathode was calculated as 0.2%. As a result, the target value of 800pC/bunch could not be achieved. This is because the intensity of UV laser is not sufficient, so we are planning to improve the laser system.

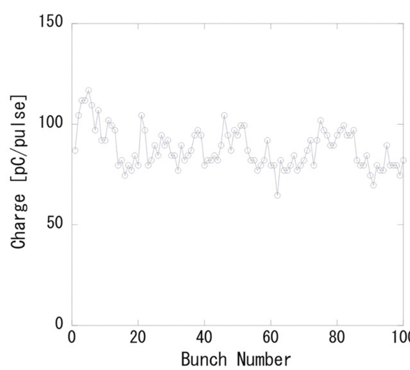

Figure 6: Charge Measurement per bunch.

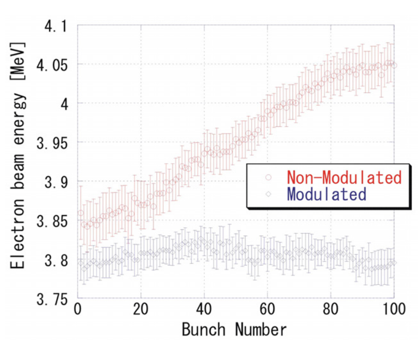

Figure 7: Energy Measurement per bunch.

On the other hand, it is obviously observed that the bunch-by-bunch energy difference was compensated by RF amplitude modulation shown in Fig.7. The energy difference of 5.6% $_{p-p}$ in non-modulation case was compensated to 1.0% $_{p-p}$ by ΔA Method.

CONCLUSIONS & FUTURE PLANS

In order to develop the multi-bunch electron beam generation system, we developed the three systems: the multi-pulse UV laser generation system, the beam energy compensation system, and the multi-bunch electron beam diagnosis system. In the multi-pulse UV laser system, we succeeded in generating $0.25\mu J \times 1 - 1000$ pulse stably by improving the pulse train picker part and amplification part. In the beam energy compensation system, we demonstrated to compensate the bunch-by-bunch energy difference from 5.6% $_{p-p}$ to 1% $_{p-p}$ using ΔA Method. Moreover, in the multi-bunch electron beam diagnosis system, it was enabled to measure the parameter per bunch by installing a FCT and a BPM. However, the bunch charge could not be reached the target value of 800pC/bunch. So we are planning to install optical fiber amplifier and the LD pumped amplifier with 4-pass operation for higher intensity and stabilizing the UV laser. Further, we need to consider the energy compensation method under the consideration of beam loading effect, if we produce the intense of bunch charge.

REFERENCES

[1] Y. Hosaka, et al.,Proc. of IPAC'10, MOPEA035 (2010)

[2] K.Sakaue, et al., Radiat.Phys.Chem.77.1136-1141 (2008)

[3] Y.Kato, et al., Proc. of LINAC'08, pp.165-167 (2008)

[4] A.Masuda, et al., Proc. of EPAC'08, pp.166-168 (2008)

[5] S.Kashiwagi, et al., Proc. of LINAC'98, pp.91-93 (1998)

[6] T.Suzuki, et al., Proc. of PAC'09, MO6RFP102 (2009)