STUDY ON ENERGY COMPENSATION BY RF AMPLITUDE MODULATION FOR HIGH INTENSE ELECTRON BEAM GENERATED BY A PHOTOCATHODE RF-GUN*

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Abstract

At Waseda University, we have been studying a high quality electron beam generation and its application experiments with a Cs-Te photocathode RF-Gun. To generate more intense and stable electron beam, we have been developing the cathode irradiating UV laser which consists of optical fiber amplifier and LD pumped amplifier. As the result, more than 100 multi-bunch electron beam with 1nC each bunch charge was obtained. However, it has to be considered that the accelerating voltage will decrease because of the beam loading effect. So we have studied the RF amplitude modulation technique to compensate the beam energy difference. The energy difference will caused by transient accelerating voltage in RF-Gun cavity and beam loading effect. As the result of this compensation method, the energy difference has been compensated to 1%p-p, while 5%p-p without compensation.

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 source based on a 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. To generate the high-current electron beam required for the application experiments, we have shifted the electron beam generation system from the single-bunch beam operation to the multi-bunch beam operation[3]. We have also constructed the energy compensation system in each bunch and the diagnosis system to measure the parameter per bunch. The target value of bunch charge is 800pC/bunch,100bunches/train. So we performed the improvement of laser amplification system to irradiate the cathode in order to obtain more intense multi-bunch electron beam.

On the other hand, in case of the multi-bunch electron acceleration, the energy difference is caused by the slow rise time of accelerating voltage in the RF cavity and beam loading effect in the accelerating structure. We have already succeeded in compensating the energy difference used the method making the flat distribution of the accelerating voltage by modulating the RF amplitude at the low level, before amplified by the klystron, called ΔA Method[3]. At first, beam loading effect could be ignored because bunch charge was low and bunch spacing was relatively long(8.4nsec). However, it is expected that beam loading effect have to be considered along with increasing the charge by the improvement of laser amplification system. So we have studied the RF amplitude modulation technique to compensate the beam energy difference both the slow rise time of accelerating voltage and beam loading effect.

In this conference, we will report our multi-bunch electron beam linac system, the details of energy compensation method using the RF amplitude modulation and the results of beam experiment.

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MULTI-PULSE LASER SYSTEM

In our system, 119MHz IR laser generated from Nd:YLF mode-locked laser was converted into UV laser in the shape of pulse train passing through the three parts: pulse train picker part, amplification part, and frequency conversion part. The flowchart of laser system is shown in Fig.1.

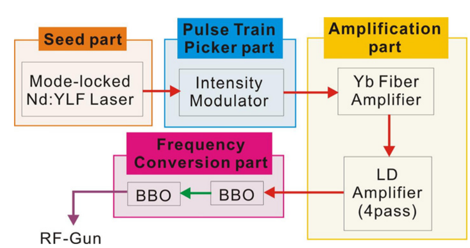

Figure 1: The Flowchart of Laser System

For the pulse train pick, a LN intensity modulator was used instead of a pockels cell. Optical alignment of fiber injection was more difficult than the pockels cell, but it was effective in cutting off voltage of 5V which is 1/640 of the pockels cell. Further, single-pulse pick was also enabled so the number of pulse was variable suiting the needs of the application experiments.

In the amplification part, we added the optical fiber amplifier system using the single-mode Yb-doped fiber. After the fiber based amplification, LD pumped amplifier system was changed from 3-pass amplification structure to 4-pass to increase the gain. As a result, the intensity of IR laser was 40μJ/pulse since the gain of fiber amplification was $\sim 10^2$ and of LD 4-pass amplification was $\sim 10^5$, respectively.An isolator and an iris were installed in LD 4-pass amplification structure to prevent the self-oscillation.

1047nm IR laser was converted to 523.5nm Green laser and Green laser was converted to 262 UV laser based on SHG and FHG by using two nonlinear optical crystals. After the conversion, we used a prism to separate FHG light from fundamental. BBO(BaB_2O_4) crystals were used as nonlinear crystals and actual intensity of UV laser was 4μJ/pulse; total transformation efficiency was about 10%.

ENERGY COMPENSATION SYSTEM

The energy diffenrence compensation is a key issue for the multi-bunch electron acceleration. The one reason is the slow rise time of accelerating voltage. Shown as Fig.2 in green line, when the rectangular RF pulse applied into the RF-Gun cavity, we must use the transitional voltage because the filling time of the cavity is relatively long and the width of the input RF pulse is limited 4μs by the klystron high voltage modulator specification. To compensate the energy difference, we have adopted ΔA method making the flat distribution of accelerating voltage in cavity by modulating RF amplitude at low level as shown in Fig.2 in blue line[4].

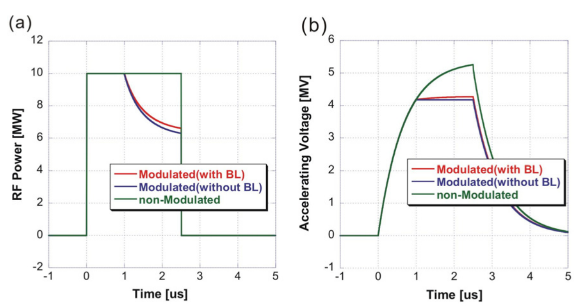

Figure 2: Calculations of (a)Input RF Pulse and (b)Accelerating Voltage

On the other hand, another reason for causing the energy difference is the voltage drop by beam loading effect. First time of multi-bunch acceleration, it could be considered that beam loading effect was small enough because the charge was low and bunch interval was long. However, after the improvement of laser amplification, it is expected that beam loading effect cannot be ignored along with increasing the charge. Thus, the energy difference compensation method which considered both the transitional rise of the accelerating voltage and the voltage drop by beam loading effect have to be applied.

Therefore, we have studied to compensate both beam loading effect and transient accelerating voltage. ΔT method is making the flat energy distribution by injecting laser at certain time as compensating the transitional rise of the accelerating voltage with the energy drop by beam loading effect[5]. The calculations of beam loading loss by 1nC/bunch multi-bunch electron beam and influence on the accelerating voltage are shown in Fig.3. It can be realized that the energy distribution in each bunch is flat when the laser injection timing is 2.5μs. However, the number of bunch, which can be accelerate, is limited by the width of the input RF pulse, if ΔT method is used in our system.

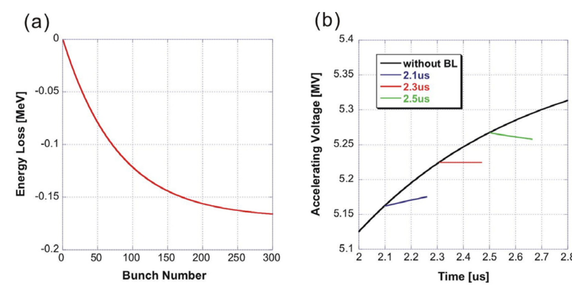

Figure 3: Calculations of (a)Beam Loading Loss and (b)Influence on the Accelerating Voltage

So we considered the technique adding the figure of transitional rise at the laser injection timing on ΔT method to the flat distribution on ΔA method, shown in 2 in red line. Calculated amplitude modulation of RF pulse is represented by:

$$P(t)' = P_0 \frac{[1 - e^{-\frac{t_1}{t_f}} + e^{-\frac{t'}{t_f}} - e^{-\frac{t+t'-t_1}{t_f}}]^2}{[1 - e^{-\frac{t}{t_f}}]^2} \quad (1)$$

where, P_0 is maximum RF power, t_1 is modulation start time, t_f is the filling time of the cavity, and t' is laser injection timing calculated on ΔT method.

We installed an amplitude modulator in low level RF system in order to modulate RF pulse shown in Fig.4. The shape of the modulation was created by a function generator(Tektronix, AFG3021) under the consideration of the in-out properties of each device such as the pulse modulator, the driver amplifier, and the klystron. The function generator can be controlled using LabVIEW so we can arbitrarily set the parameter values. The observations of input RF pulse and accelerating voltage are shown in Fig.5. It can be confirmed that it is succeeded in making the flat accelerating voltage about 1.5μs, whereas the pickup signal is small compared with RF noise due to the small coupling constant between the RF pickup and the cavity.

BEAM PARAMETER MEASUREMENT

The present experimental setup is described in Fig.6. A Faraday cup and a screen monitor after the analyzer magnet in the old beamline layout was not able to measure each bunch parameters due to their low temporal resolution. So we installed a FCT to measure the charge and a BPM to

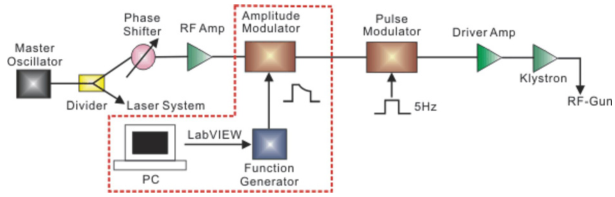

Figure 4: RF Control System for ΔA Method

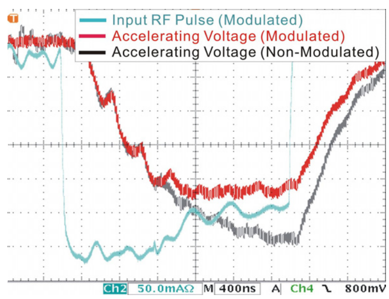

Figure 5: Observations of Input RF Pulse and Accelerating Voltage

measure the energy into the beamline, which are the non-destructive measurement equipment.

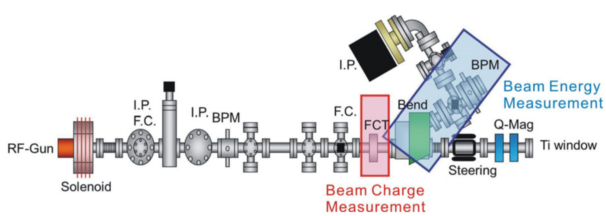

Figure 6: The Schematic design of Beamline

The result of charge measurement of each bunch is shown in Fig.7. It was obtained over 1nC/bunch multi-bunch electron beam that is about 15 times higher than before by improving the laser amplification system and reached the target value of 800pC/bunch. Then, the quantum efficiency of cathode was calculated as 0.2%.

The result of energy measurement of each bunch is shown in Fig.8. Three cases were measured; amplitude modulated considered the beam loading effect under the result of Fig.7(red line), modulated without considering beam loading effect i.e. the flat distribution(blue line), and flat top pulse(green line). The energy difference were 1.1 % $_{p-p}$, 4.2 % $_{p-p}$, and 5.1 % $_{p-p}$, respectively. As a result, it was succeeded that the compensation of energy difference in each bunch by performing RF amplitude modulation considered both the transitional rise of the accelerating voltage and the voltage drop by beam loading effect. It is enabled to be applied to also the multi-bunch electron beam which is different in the charge or the repetition rate because of the modulation flexibility of RF pulse.

On the other hand, the appearance of energy waving in the bunch train was observed conspicuously in the result

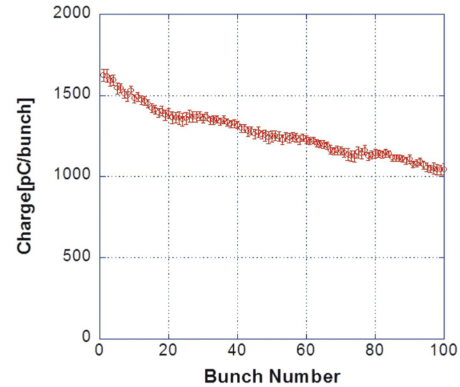

Figure 7: Charge Measurement of each bunch

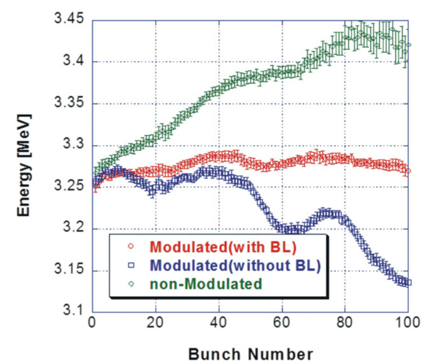

Figure 8: Energy Measurement of each bunch

of using ΔA method. The reason is considered that it is affected with the noise during the measurement or the noise affected with the RF amplitude, because we did not use all amplification device at saturated region.

CONCLUSIONS & FUTURE PLANS

It was obtained over 1nC/bunch multi-bunch electron beam stably by installing optical fiber amplifier system and LD pumped amplifier 4-pass system. Moreover, we performed the RF amplitude modulation considering both beam loading effect and transient accelerating voltage. The results were successful in compensating the energy difference in each bunch to 1.1 % $_{p-p}$. As a future plans, we will construct the laser system to irradiate the cathode which repetition rate is higher than 119MHz using the external optical cavity for increasing bunch number and produce more intense electron beam.

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