DEVELOPMENT OF MULTI-BUNCH LASER SYSTEM FOR PHOTOCATHODE RF GUN IN KU-FEL

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Abstract

We have been developing mid-infrared FEL (MIR-FEL) system, Kyoto University-FEL (KU-FEL), which utilizes a 4.5-cell S-band thermionic radio frequency (RF) gun, in Institute of Advanced Energy, Kyoto University. We plan to introduce a Brookhaven National Laboratory (BNL)-type 1.6-cell photocathode RF gun to generate higher peak power MIR-FEL. The purpose of this work is to develop a multi-bunch laser system which excites the photocathode in the RF gun. The target values of the system are bunch number of 300 and micro-pulse energy of 1 μJ in the wavelength of 266 nm. The laser system consists of a mode-locked $Nd:YVO_4$ laser as the oscillator, an acousto-optic modulator (AOM), a beam alignment feedback system, a laser diode (LD) pumped Nd:YAG amplifier. We could stabilize the laser position within 1 μm at the downstream of the AOM, and achieve to amplify the seed laser up to 1.2 μJ per micro-pulse.

INTRODUCTION

We have been developing our resonator type MIR-FEL to upgrade our user facility to contribute the advanced energy science in Kyoto University. Using a 4.5-cell S-band thermionic RF gun and a 3-m accelerator tube in the present facility, electrons are accelerated up to 40 MeV. We have extended FEL wavelength from 5 to 14.5 μm by the substitution of undulator system [1].

We have planned to introduce a BNL-type 1.6-cell photocathode RF gun to generate more stable and higher peak FEL power which has been showed by our numerical study [2]. Since a photocathode RF gun has already been manufactured [3], we started to develop a multi-bunch laser system for resonator type FEL system with this RF gun. For the laser system, we introduced a beam alignment feedback system, and constructed a multi-pass amplifier in the infrared (IR) wavelength. In this paper we will briefly describe the multi-bunch laser system and the present status of the development.

MULTI-BUNCH LASER SYSTEM

Target Value

Electron charge, Q, from the photocathode is written by formula.

$$Q = \frac{\eta e W \lambda_L}{hc} \tag{1}$$

Here, η is quantum efficiency, e is elementary charge, W is pulse energy of the drive laser, λ_L is wavelength of the drive laser, and h is Planck's constant. Considering the quantum efficiency and the life time, Cs_2Te is the candidate of our photocathode. Because Cs_2Te has the band gap energy of 3.2 eV, a drive laser of the ultraviolet (UV) wavelength is required to excite photoelectrons. In this work, the quantum efficiency was assumed to be 1.5% [4]. Therefore, when the electron charge is assumed to be 1 nC, the pulse energy in the UV wavelength is required to be 0.31 μJ per micro-pulse from the formula (1). Taking into account the optical loss and other issues, the target value of the pulse energy in the UV wavelength was set to be 1 μJ per micro-pulse. Here, we plan to use two non-linear optical crystals to generate the high harmonic generation. The conversion efficiency changing from 1064 nm to 266 nm was assumed to be 10% [5]. Therefore, the target value of the IR wavelength before the wavelength conversion is 10 μJ per micro-pulse. We plan to construct a multi-pass amplifier with optical gain of 40 dB to achieve these values. The main parameters are shown in Table 1.

Table 1: The Main Parameter of the Target Value

electron charge	1 nC / micro-pulse
micro-pulse number in a macro-pulse	more than 300
repetition frequency of macro-pulse	1 ~ 10 Hz
micro-pulse energy (UV)	1 μJ
micro-pulse energy (IR)	10 μJ

System Configuration

We used a mode locked $Nd:YVO_4$ laser (GE-100-VAN, Time-Bandwidth) as a laser oscillator. This laser's specifications are summarized that wavelength is 1064 nm, repetition frequency is 89.25 MHz (11.2 ns), average output power is 600 mW, and pulse width is 7.5 ps. This repetition frequency is one thirty second of the RF frequency of KU-FEL linac (2856 MHz). The laser system was designed to synchronize the phase timing between the RF signal of KU-FEL and the repetition frequency of the drive laser by controlling the resonator

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length of the mode-locked laser. In the multi-bunch laser system, we put an AOM to generate an amplitude-modulated macro-pulse arbitrarily. We found, however, that the laser beam position has been fluctuated because of a drift effect in the AOM. Therefore, we introduced a beam alignment feedback system (Aligna4D, TEM) located in the downstream of the AOM to stabilize both the laser beam position and angle. Then a four-pass amplifier using a LD pumped amplifier (REA5006-2P1, CEO) which contains a Nd:YAG rod (ϕ5 mm×12.6 cm) is employed. The configuration of the multi-bunch laser system is shown in Fig. 1. Figure 1 (a) shows from the laser oscillator to the beam alignment feedback system, and (b) shows a schematic view of the multi-pass amplifier system.

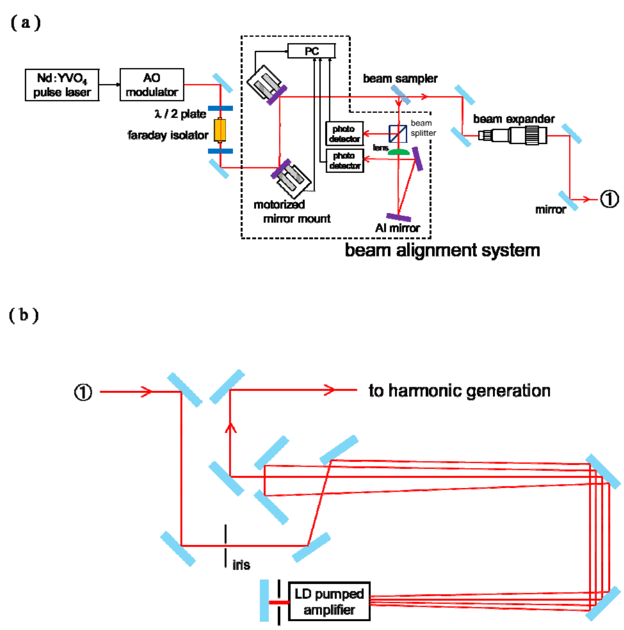

Figure 1: Schematic view of the multi-bunch laser system. (a) shows from the laser oscillator to the beam alignment feedback system and (b) shows a schematic view of the multi-pass amplifier system.

PERFORMANCE TEST OF BEAM ALIGNMENT FEEDBACK SYSTEM

Because the length from the laser oscillator to the wavelength conversion crystals is about 8 m, we have introduced the beam alignment feedback system as described in previous section. This system consists of two motorized mirror mounts, two laser beam position detectors, a beam splitter, and a plane-convex lens. The motorized mirror mount consists of a picomotor, and a piezo element. Moving the motorized mirror mounts automatically, the laser beam position and angle is kept at the central position of the detectors. In this section we will report on our test measurement of the laser beam stabilization in the multi-bunch laser system with the beam alignment feedback system.

Stability Measurement of the Laser Beam

The laser beam position and angle (both in horizontal and in vertical) can be monitored by the position detectors of the laser beam alignment feedback system. At the beginning, the laser system was warmed up for an hour to obtain a stable operation condition in the laser oscillator and the AOM. Then we measured four parameters, horizontal beam position, vertical beam position, horizontal beam angle, and vertical beam angle, with the beam alignment feedback system on and off in every 20 minutes. In the measurement the laser beam parameters are summarized as followings;

the micro-pulse number in a macro-pulse : 300,
the repetition frequency of macro-pulse : 10 Hz,
the macro-pulse energy : 6 nJ.

The results are shown in Fig. 2, 3 and the standard deviation of the measured value is shown in Table 2. We could stabilize the laser beam position within 1 μm and the laser beam angle within 20 μrad by using this system. And, we could prevent the drift effect which occurred for 20 minutes especially in Fig. 2 (b). Consequently, we can estimate that the horizontal displacement is within 38 μm, and the vertical one is within 98 μm at the position of the wavelength conversion crystals which is 7 m downstream from this alignment system.

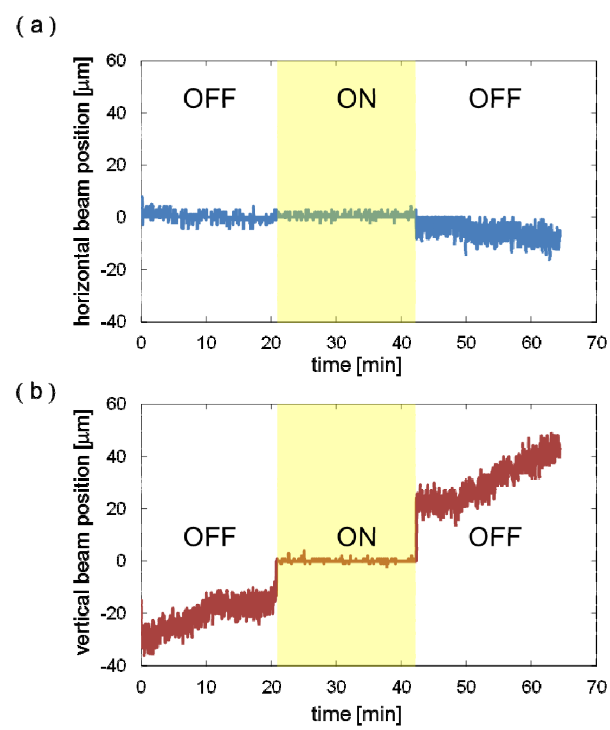

Figure 2: Comparison of the laser beam position when the regulator was switched on and off, (a) horizontal (b) vertical.

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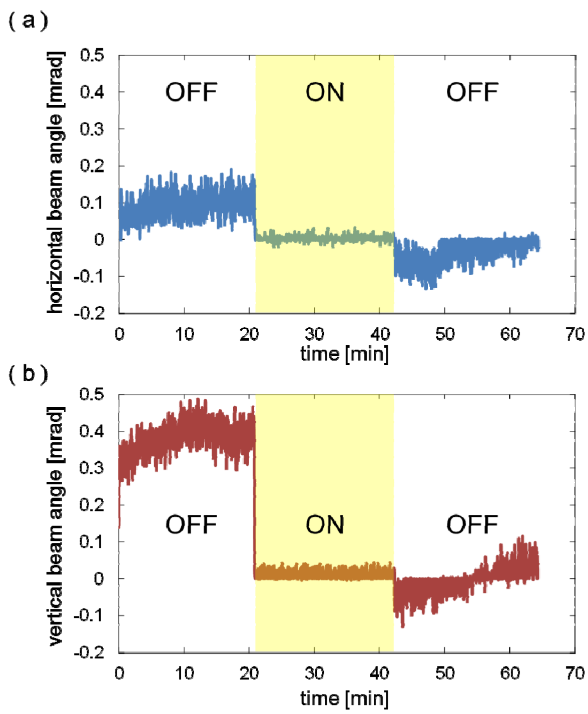

Figure 3: Comparison of the laser beam angle when the regulator was switched on and off, (a) horizontal (b) vertical.

Table 2: The Standard Deviation of Measured Value

	OFF	ON
angle (horizontal)	30 μrad	5.4 μrad
(vertical)	35 μrad	14 μrad
position (horizontal)	2.0 μm	0.56 μm
(vertical)	6.7 μm	0.40 μm

CONSTRUCTION OF MULTI-PASS AMPLIFIER

We installed the multi-pass amplifier whose layout is shown in Fig. 1 (b). This amplifier is a LD pumped amplifier and the laser beam is passed through four times to obtain enough optical gain. A Nd:YAG crystal in this amplifier is excited for about 250 μs. A seed pulse laser is injected at the timing of 230 μs. The laser parameters are shown in Table 3.

Table 3: The Laser Parameters of the Laser Oscillator

repetition frequency of macro-pulse	10 Hz
micro-pulse number in a macro-pulse	300
modulated waveform in the AOM	rectangular
amplitude of the AO drive signal	4 V

We measured the signal of the laser beam which was passed four times through the amplifier by using a photo diode (PD). The measured signal intensity was getting larger by increasing the current of the amplifier. During the measurement we found that the self-oscillation occurred in this system due to the amplifier's radiating light when the current value was larger than 60 A. The waveform of the PD signal is shown in Fig. 4.

To avoid the self-oscillation, we set the iris to cut off the self-oscillation path which had the large angle of divergence as shown by Fig. 1 (b). We succeeded to prevent the self-oscillation when the current value was less than 80 A. The waveform of the PD signal at the current value of 80 A is shown in Fig. 5. The pulse energy from the amplifier depending on the current value is plotted in Fig. 6. We used the energy meter (PE10BB, Ophir Optronics) which couldn't measure the pulse energy of less than 5 μJ. As shown in Fig. 6 we confirm that the pulse energy increases exponentially by increasing the current value. The maximum pulse energy was 360 μJ. Because the number of micro-pulse in a macro-pulse was 300, the pulse energy per micro-pulse was deduced to be 1.2 μJ which was below the target value (10 μJ). The reason is that the iris cut out the laser. To achieve the target power with the four-pass amplifier system, we will introduce a fast optical chopper.

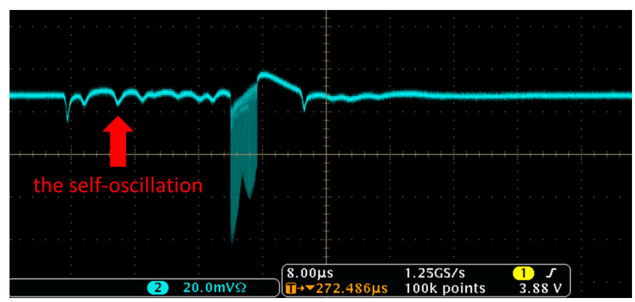

Figure 4: The waveform of PD signal when the self-oscillation occurred.

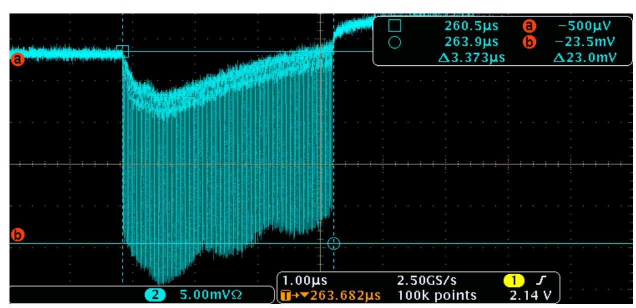

Figure 5: The waveform of PD signal at the amplifier's current value of 80 A.

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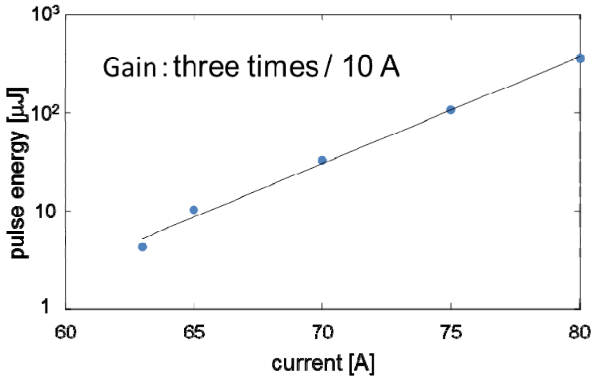

Figure 6: The amplified pulse energy as a function of the LD current.

CONCLUSION

We have developed the multi-bunch laser system to introduce the photocathode RF gun to obtain more stable and higher peak FEL power in KU-FEL. In this development, we introduced the beam alignment feedback system located the downstream of the AOM which generated 300 micro-pulses in a macro-pulse. We could stabilize the laser beam position within 1 μm and the laser beam angle within 20 μrad by using this system. We constructed the multi-pass amplifier and achieved to amplify the seed laser up to 1.2 μJ per micro-pulse that was lower than our target value of 10 μJ. It is required to improve the amplifier system without the self-oscillation to achieve the target value.

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