COMMISSIONING STATUS OF THE EXTREME-ULTRAVIOLET FEL FACILITY AT SACLA

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Abstract

To equip SACLA with wide ability to provide laser beams in EUV and soft X-ray regions to experimental users, we have constructed a new free electron laser facility for the SACLA beamline-1. Injector components, such as a thermionic electron gun, two buncher cavities, and their RF sources, were relocated from the SCSS test accelerator. At the downstream of a bunch compressor chicane, 3 C-band acceleration units were newly installed to effectively boost a beam energy up to 500 MeV. 3 in-vacuum undulators with a larger K-value of 2.1 were remodelled for increasing SASE intensity. Beam commissioning was started in autumn 2015. We carefully tuned an electron beam orbit and bunch compression processes to obtain 240 A at the peak along the injector and 2 bunch compressors. The bunch length was successfully compressed from 1 ns to 1 ps. After the tuning, the lasing of the EUV-FEL was realized. So far the FEL radiation with energy of about 25 μJ and a 30 nm wavelength driven by a 500 MeV electron beams was observed. In this summer, we will install additional 2 C-band accelerator units to raise the maximum beam energy to 750 MeV for providing a laser at 13 nm.

INTRODUCTION

SPring-8 Angstrom Compact X-ray free electron Laser (SACLA) can provide a laser in the hard X-ray region to experimental users from March 2012 [1]. Furthermore, we constructed an additional extreme-ultraviolet (EUV) FEL facility, as a user machine, to drive the SACLA beamline-1. The EUV-FEL facility expands the available FEL wavelength region of SACLA for longer direction and it also increases experimental opportunities of users.

Many injector components including 2 undulators of the facility were relocated from the SCSS test accelerator, which was the prototype accelerator for SACLA [2]. The relocation of the accelerator components has been completed in September 2014, and RF conditioning of the accelerating structures began from October 2014 [4]. After completing the construction of the control system for the relocated machine, we started a beam commissioning to generate the FEL in autumn 2015. In this paper, the overview of the EUV-FEL facility and the current status of the beam commissioning are reported.

ACCELERATOR CONFIGURATION AND ITS FUNCTIONS

Figure 1 shows the schematic view of the EUV-FEL facility. To widen the wavelength region and to increase FEL intensity stability for the user machine, the original configuration of the test accelerator was modified, as follows. The electron beam energy was increased to obtain the FEL with the wavelength shorter than that of SCSS. Therefore, 3 C-band accelerator units with a higher acceleration gradient than that of SACLA were added [3]. A low-level RF system with a higher amplitude and phase stability and a highly stable high-voltage inverter power supply to charge the pulse forming network (PFN) of a klystron modulator with higher reliability than those of the test accelerator were installed to realize FEL intensity stability comparable to SACLA. The magnetic circuit of the undulator with a larger K-value of 2.1 was remodeled by changing the period of magnet array from 15 mm to 18 mm in order to increase SASE-FEL intensity. Table 1 shows the design parameters of the EUV-FEL facility.

Table 1: Design Parameters of the EUV-FEL Facility

Accelerator	
Beam energy	500 MeV
Beam charge	~0.3 nC
Peak current	300 A
Longitudinal bunch length	1 ps
Repetition rate	60 Hz (max)
Undulator	
Periodic length	18 mm
K-value	2.1 (max)
Number of periods	690
FEL	
Wavelength	30 nm (K=2.1)
Pulse energy	~100 μJ

A thermionic electron gun and high voltage beam chopper generate an electron beam with a 1 ns bunch length and a 1A beam current. An injector RF system, which is composed of a 238 MHz sub-harmonic buncher (SHB), a 476 MHz booster cavity, an S-band alternating periodic structure (S-APS) and S-band travelling structure (S-TWA), compresses the bunch length of the electron beam up to several picoseconds. The S-APS and S-TWA also gives energy chirp along the electron bunch, and the 1st magnetic bunch compressor (BC1) using a 4 bending magnets chicane compresses the bunch. The longitudinal bunch length and the peak current of the electron beam through the BC1 become 1 ps and 300 A, respectively. After the BC1, the C-band accelerator accelerates the electron beam energy to 500 MeV, and the 2nd bunch compressor (BC2) further compresses the bunch. Finally, the electron beam passes through the 3 undulators and the undulators generate EUV-FEL with a wavelength of 30 nm.

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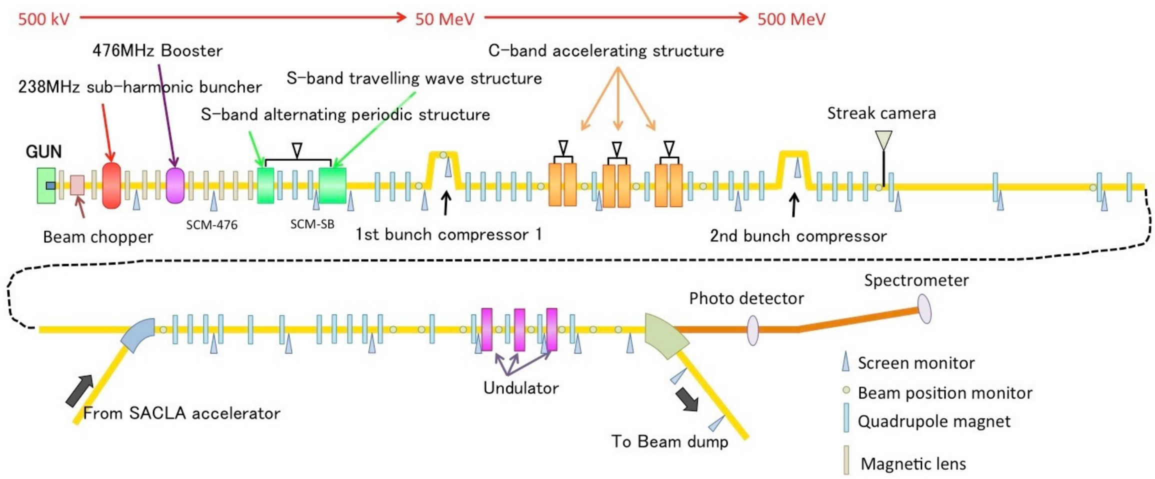

Figure 1: Schematic view of the extreme-ultraviolet FEL facility in SACLA.

BEAM COMMISSIONING

As the first step of the beam commissioning, we adjusted the trajectory of the electron beam, which was generated from the thermionic electron gun, by using beam transport magnets, such as magnetic lenses and the steering magnets. Next, we performed the tuning of a velocity-bunching process by adjusting the acceleration RF phases and electro-magnetic field strength of the injector cavities. For example, a fast differential current monitor [5], which was installed at downstream of the 238 MHz SHB, was used to measure the longitudinal bunch length. The optimum velocity-bunching phase and acceleration gap voltage of the SHB were decided according to the measured bunch length. Next, the adjustment of the velocity-bunching at the 476 MHz booster was performed using the intensity data of coherent transition radiation (CTR), which was generated from a screen monitor (SCM) and detected by waveguide spectrometer [5]. Because the CTR intensity depends on the longitudinal bunch length of the electron beam, we can measure the relative bunch length and obtain the optimum bunching phase from the radiation intensity of specific wavelength. Figure 2 shows the CTR intensity variation as a function of the RF phase of the booster. The CTRs were detected at two locations, which are after the booster (SCM-476) and after the S-APS cavity (SCM-SB). When the CTR intensity was maximum, the longitudinal bunch length was minimum at the position of the screen monitor. The RF phase of the 476 MHz booster was set to the optimum bunching phase indicated by the red line on Fig.2 so that the electron bunch length became the minimum at the middle of the S-APS cavity without RF fields.

The longitudinal bunch compression ratio (R56) of the BC1 is -40.6 mm. The RF phase of the S-APS and S-TWA was adjusted at -14 degree from the crest so that the bunch is compressed to ~1 ps after the BC1. After the BC1, the C-band accelerator accelerated the electron beam of up to the final energy of 500 MeV.

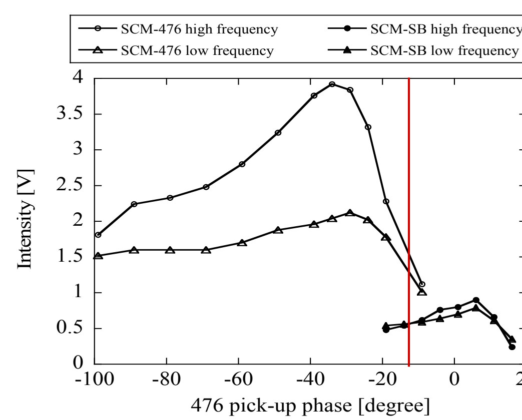

Figure 2: CTR intensity variation, which is generated from the screen monitors after the 476 MHz booster (open circles and triangles) and after the S-APS cavity (solid circles and triangles), as a function of the RF phase of the 476 MHz booster. The red line indicates the optimum setting point of the RF phase of the booster, which gives the minimum bunch length at the middle of the S-band APS cavity without RF fields.

The beam trajectory was adjusted to pass through the center of the cavities and focusing magnets. The final beam energy was measured to be 500 MeV at dispersive point of the BC2. The longitudinal bunch length was measured using a streak camera, which is installed at a place downstream of the BC2. Figure 3 shows the typical temporal profile of the electron beam measured with the streak camera. In this result, the bunch length is 1.3 ps in FWHM. Furthermore, the bunch length was also measured by a RF zero-cross method. The bunch length was 1 ps in FWHM, and the peak current was 240 A at a place downstream of the BC2. Since the peak current was lower than the design parameter, we tried to compress the bunch by the BC2 to tune the C-band accelerator. Finally, we realized the demanded peak beam current.

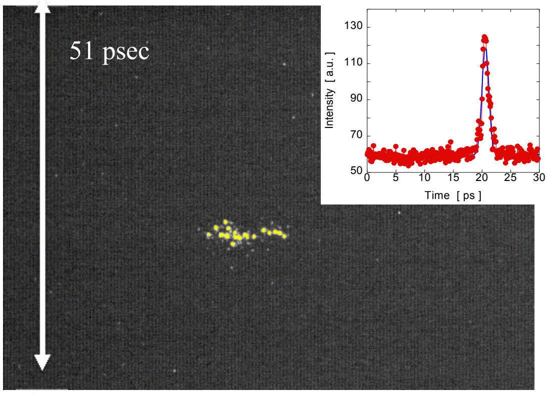

Figure 3: Temporal profile of the electron beam measured by the streak camera. The OTR was vertically and temporally stretched in this image.

After guiding the electron beam to the undulators, we performed fine-tuning to generate the EUV-FEL. A beam trajectory along the undulator beam line was adjusted to its center orbit. Then, we closed the gap of the undulator so that the K-values of all the 3 undulators were same as 2.1. A gas intensity monitor and photodiode observe the pulse intensity of the FEL, and a grating spectrometer measures its single-shot spectrum. Figure 4 shows the pulse intensity and intensity fluctuation of the FEL depending on the K-values of the undulators. Figure 5 shows the observed single-shot spectrum. When the K-value decreased from K=2.1 to lower values, the pulse intensity decreased and the intensity fluctuation increased. These results indicated that the EUV-FEL at a K value of 2.1 could approach to the saturated condition. At this time, the wavelength of the FEL was 30 nm (41.5 eV) at the electron beam energy of 500 MeV and the K value of 2.11. The preliminary estimated value of the pulse energy of FEL was approximately 25 μJ in average by using the gas intensity monitor. Although, the photodiode can measure the absolute pulse energy, in cannot detect such a high intensity light. Therefore, we utilized the photodiode to calibrate the gas monitor, which is sufficiently linear for the high intensity region, in a low intensity region. The calibration data of the gas monitor in the high intensity region was extrapolated by using the low intensity data. Figure 6 shows the trend graph of the FEL intensity for 1 hour. The FEL intensity is now kept at our acceptable stability level.

SUMMARY

We constructed a facility to generate an EUV-FEL with a wavelength region longer than that of SACLA. Beam commissioning started in autumn 2015. The bunch compression in an injector section and BCs was optimized and the peak current of an electron beam was tuned to obtain the designed value. We finally succeeded in lasing at 30 nm by a 500 MeV electron beam and a K-value of 2.11. In SACLA, experimental users can be possible to use the two FELs independently at the same time by our EUV-FEL machine. We have a plan to add further C-band acceleration units in this summer. Then an electron energy reaches 750 MeV and the FEL wavelength is shortened down to ~13 nm to generate the FEL with more wide wavelength region.

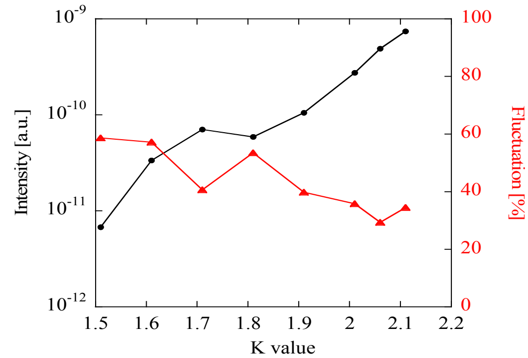

Figure 4: EUV-FEL pulse intensity (black dots, left axis) and the intensity fluctuation (red triangle, right axis) as function of the K-value of the undulators.

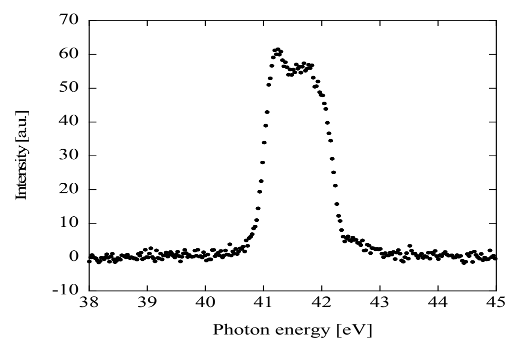

Figure 5: Single-shot spectrum of the EUV-FEL.

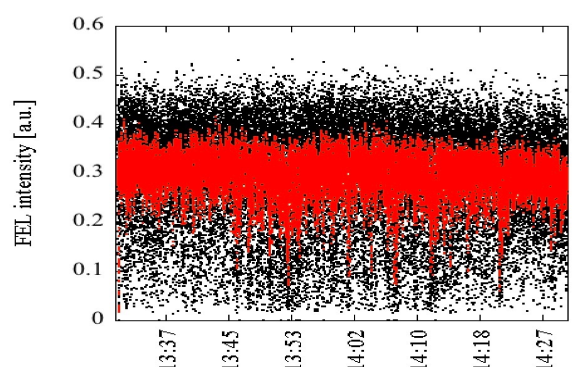

Figure 6: Trend graph of the FEL intensity for 1 hour. Black dots are a single-shot data and red dots are the moving average of the 10 shots.

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