MULTI-BEAMLINE OPERATION TEST AT SACLA

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Abstract

After the installation of the second undulator beamline (BL2), multi-beamline operation has been started at SACLA since January 2015. 30 Hz electron bunches are alternately deflected to two beamlines using a kicker magnet and a DC twin-septum magnet. Since all undulator beamlines are placed downstream of the linear accelerator at SACLA, the beam energies are changed from bunch to bunch to obtain broad tunability of the laser wavelengths between the beamlines. In the multi-beamline operation, stable lasing is successfully achieved at the two beamlines with pulse energies around 100-150 μJ. The peak current is currently limited to about 1 kA due to the CSR effects at a doglegged beam transport to BL2. The status and operational issues related to the multi-beamline operation of SACLA are reported.

INTRODUCTION

In order to meet the growing demand for XFEL user operation, a new undulator beamline (BL2) was installed in September 2014 at SACLA. Following this installation, a DC switching magnet was replaced by a kicker magnet and a DC twin-septum magnet in January 2015 to start pulse by pulse multi-beamline operation [1].

The undulator hall of SACLA can accommodate five undulator beamlines and they are all placed in parallel to each other [2]. In conventional facility designs, the beamlines of low photon energies branch off from the middle of a linear accelerator, where the electron beam energy is still low (Fig. 1 (a)) [3, 4]. At SACLA, however, all beamlines are placed downstream of the accelerator to make the facility compact (Fig. 1 (b)). Instead, the electron beam energy is controlled from bunch to bunch to obtain a wide spectral range between beamlines [5].

Figure 2 is a schematic of the SACLA facility. BL3 is the first undulator beamline installed in the midst of the five beamlines, so the electron beam travels straight from the end of the accelerator. The second beamline, BL2, is placed next to BL3. The undulators of BL2 and BL3 have the same parameters with a magnet period of 18 mm. In the beam transport to BL2, the electron beam is deflected twice by 3° in a dogleg.

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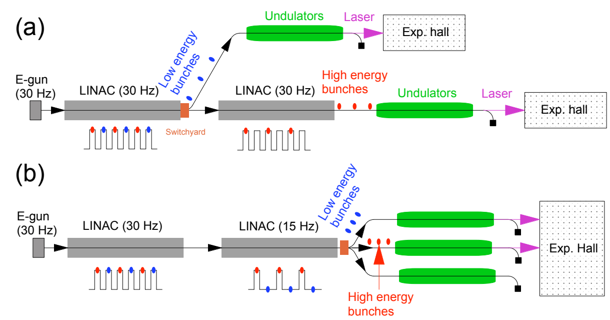

Figure 1: Multi-beamline schemes of XFEL facilities, (a) conventional layout and (b) SACLA.

In addition to the XFEL beamlines, there is a beam transport line to the SPring-8 storage ring, which is called XSBT (XFEL to Synchrotron Beam Transport). Since SACLA is planned to be used as a low-emittance injector in the upgrade project of SPring-8, XSBT will be used for the electron beam injection to the upgraded low-emittance ring in future [6].

BEAMLINE SWITCHYARD

A beamline switchyard is composed of a kicker magnet and a DC twin-septum magnet installed at the end of the linear accelerator. The switchyard deflects the electron beam in three directions (+3°, 0° and -3°), and each direction corresponds to BL2, BL3 and XSBT respectively. To ensure the electron beam orbit stability, the deflection angle of the kicker is kept small as ±0.53°. Then the DC twin-septum, locating 5.2 m downstream of the kicker (Fig. 3), deflects the beam by ±2.47°. The stability requirement for the kicker is 1×10^{-5} (peak-to-peak) equivalent to an angular orbit error of 0.1 μrad.

The kicker has a length of 0.4 m and its yoke is made with laminated silicon steel plates of 0.35 mm thickness. A ceramic vacuum duct is used at the kicker magnetic gap to eliminate the effects of eddy currents.

The DC twin-septum is composed of two identical septum magnets symmetrically-placed from side to side. Each septum magnet deflects the electron beam in opposite direction and the electron bunches for BL3 pass through between the two septums [1].

A pulsed power supply of the kicker magnet is a non-resonant type. It generates a bipolar trapezoidal waveform of current at up to 60 Hz, which is the maximum repetition of the electron beam at SACLA. The polarity, amplitude and repetition of the pulses can be arbitrarily changed according to the direction of deflection, beam energy and repetition of the electron bunches.

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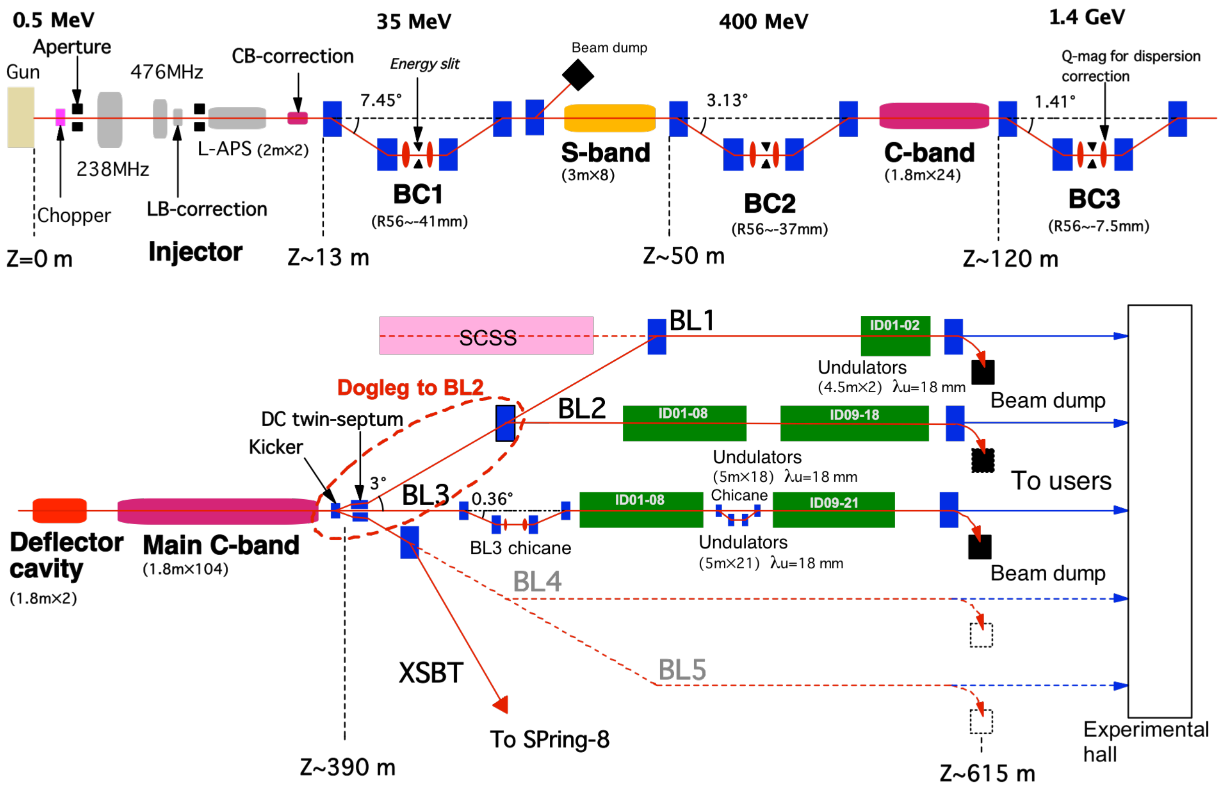

Figure 2: Schematic of SACLA facility.

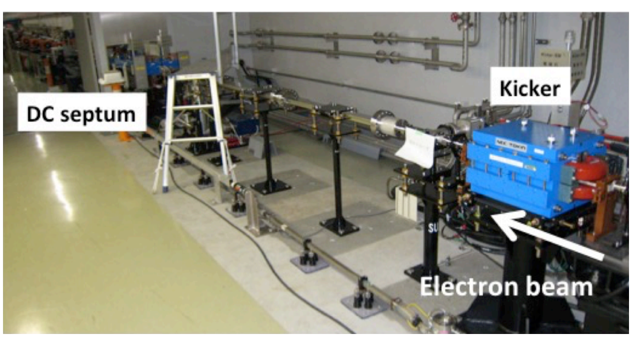

Figure 3: Photograph of a beamline switchyard.

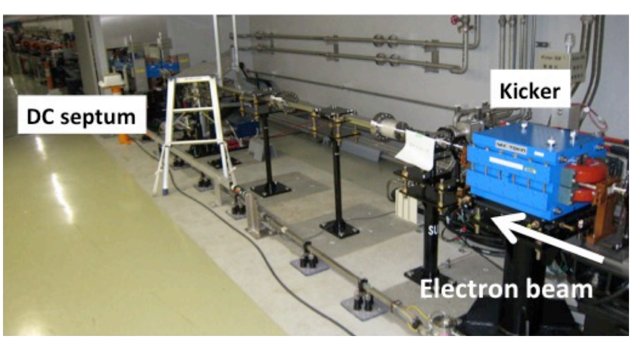

Figure 4: An example of a beamline switching pattern. Colored dots show the arrival timing of the electron bunches to the kicker.

Figure 4 is an example of a beamline switching pattern. The duration of a single trapezoidal waveform is 16.6 ms (60 Hz) and four waveforms compose the switching pattern. In this example, the electron bunches of 60 Hz are deflected to BL2 at 15 pps, BL3 at 15 pps and XSBT at 30 pps. The arrival timing of the electron bunches is set at the end of the flat top of each trapezoidal waveform, where the output current is well regulated and stabilized.

Before installation, the stability and reproducibility of the pulsed magnetic fields are checked using a gated NMR detector, which scans the resonant frequency only when a 0.6 ms gate is opened. Thus the peak magnetic fields can be accurately measured [1]. Except for a slow drift, which can be corrected using a beam orbit feedback system, the pulse-to-pulse stability of 1×10^{-5} (peak-to-peak) is confirmed.

CSR EFFECTS AT BL2 DOGLEG

Figure 5 shows the beam optics and the magnet configuration of the beam transport to BL2. The dogleg is made not only achromatic, but also isochronous by using two small inversed bending magnets to prevent the change of the longitudinal electron bunch shape and length.

In order to pursue higher laser pulse intensity, the peak current has been increased by strong compression of the electron bunches at SACLA. Currently the peak current reaches around 10 kA, which is more than three times higher than the original design value [7]. Short electron bunches and photon pulses are desirable for XFEL users, but they impose a severe condition for beam transport due to the CSR effects [8-11]. Since the deflection angle of 3°

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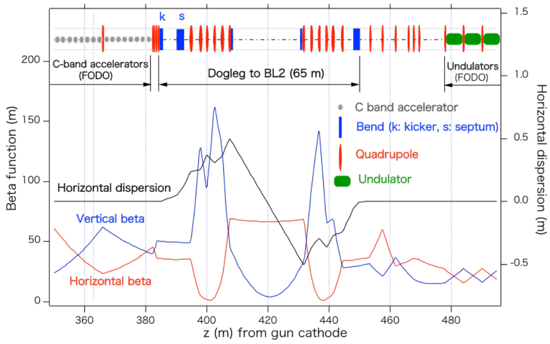

Figure 5: Beam optics and magnet configuration of the BL2 transport line.

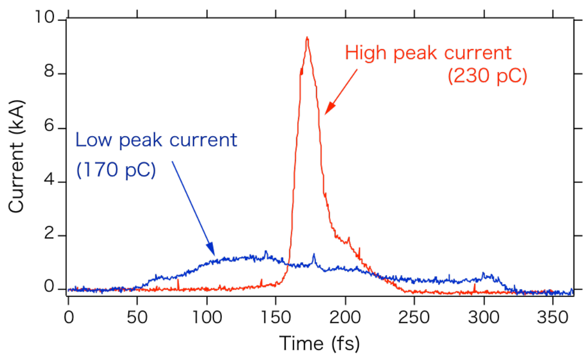

Figure 6: Longitudinal electron bunch profiles measured by a C-band RF deflector.

is unevenly distributed to the kicker and the septum magnet at the switchyard, a DBA lattice can not be applied to cancel the CSR effects [12, 13].

Figure 6 is the longitudinal bunch profiles measured by a C-band RF deflector cavity [14]. When the 10 kA bunches (Fig. 6, “High peak current”) of 7.8 GeV are transported to BL2, large fluctuation of the horizontal beam orbit is observed after the dogleg. Although the lasing was successfully obtained at BL2, the laser intensity largely fluctuates from pulse to pulse and the pulse energy stayed around 30 μJ, which is one order smaller than the value routinely obtained at BL3.

As reducing the peak current, the fluctuations of the horizontal beam orbit and the laser pulse intensity decrease. At around 1 kA of the peak current, whose longitudinal electron bunch profile is shown as Fig. 6 “Low peak current”, the maximum pulse energy of 100-150 μJ is obtained.

Table 1 compares the electron beam orbit fluctuations of the two beamlines under different peak currents. The beam orbit fluctuations are measured using two BPMs in front of the undulators of each beamline. Although the orbit fluctuations of BL2 are always larger than those of BL3, they reduce to sufficiently small level at 1 kA compared to the transverse emittance size of 33 pm-rad assuming 0.5 μm-rad normalized emittance and a 7.8 GeV beam energy.

Table 1: Fluctuations of the Electron Beam Orbit in Front of the Undulators. Both position and angle are measured using two BPMs and the area of distribution (rms) is shown. The conditions of high and low currents correspond to the electron bunches shown in Fig. 6.

	Horizontal plane (pm-rad)	Vertical plane (pm-rad)
BL2, high current	16.3	0.74
BL2, low current	2.7	0.64
BL3, high current	1.4	0.27
BL3, low current	0.83	0.24

MULTI-BEAMLINE OPERATION

The multi-beamline operation is tested using the 7.8 GeV electron bunches with a 1.2 kA peak current (Fig. 6, “Low peak current”). The repetition of the electron bunch is 30 Hz and the kicker magnet alternately deflects the bunches to BL2 and BL3. The undulator K-values are set to K=2.85 and K=2.1 at BL2 and BL3 respectively. Figure 7 shows the laser pulse intensities measured at the two beamlines. The photon energies are 6.38 keV at BL2 and 10.07 keV at BL3. The pulse intensity fluctuations are about 10 % (STD) at both beamlines and stable XFEL operation is achieved.

Fixing the electron beam energy the same for the two beamlines limits the wavelength tunability, which is an important feature of XFELs as a light source. In order to enlarge the spectral range, multi-energy operation of the accelerator is applied [5].

There are 52 C-band klystrons (104 accelerator structures) downstream of the final bunch compressor BC3 at SACLA, and the electron bunches are accelerated at a crest RF phase. In normal single-energy operation, all the klystrons run at the same repetition as the electron bunches. For the multi-energy operation, some of the klystrons are operated at sub-harmonics of the bunch repetition to change the beam energy of individual bunches.

In the demonstration, the repetition of 12 klystrons is changed to 15 Hz, which is half of the electron bunch repetition of 30 Hz. As a result, half of the electron bunches are not accelerated by the accelerator structures powered by these klystrons. Therefore the beam energies of the electron bunches can be alternately changed between 6.3 GeV and 7.8 GeV at the end of the accelerator. Then the kicker magnet deflects the lower energy bunches to BL2.

Figure 8 is the averaged spectra measured by a monochromator. The photon energy of BL2 is now lowered from 6.38 keV to 4.09 keV, while that of BL3 is

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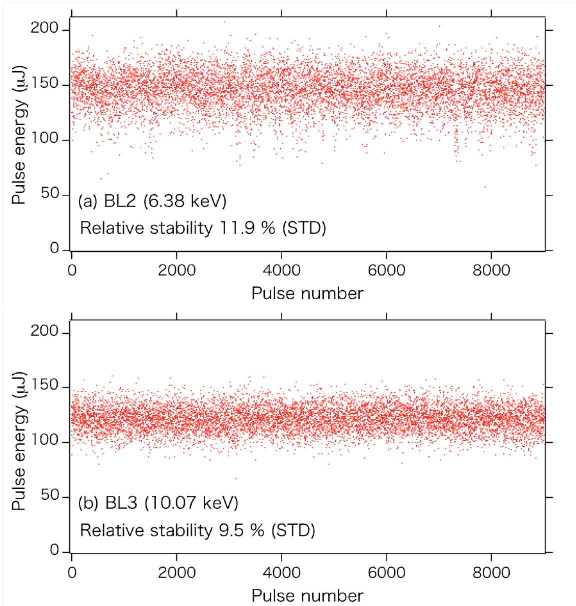

Figure 7: Stability of the photon pulse intensity, (a) BL2 and (b) BL3. Red dots are single-shot results. The electron beam energy is 7.8 GeV. The undulator K-values are 2.85 and 2.1 for BL2 and BL3 respectively.

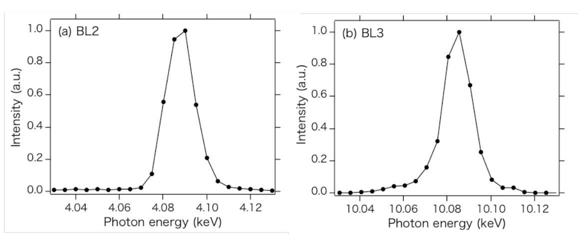

Figure 8: Averaged laser spectra measured at (a) BL2 and (b) BL3.

maintained the same as 10.09 keV. Figure 9 is the laser pulse intensities of the two beamline. Compared to Fig. 7, no degradation of the laser stability is observed. By optimizing the beam energies for each beamline, the wavelength tunable range of the multi-beamline operation can be largely extended.

SUMMARY

The multi-beamline operation using two undulator beamlines installed at the end of the accelerator has been successfully demonstrated at SACLA. 30 Hz electron bunches are alternately deflected to the two beamlines and simultaneous lasing has been obtained. By changing the beam energies of individual electron bunches, a broad spectral range can be achieved in the multi-beamline operation.

The CSR effects observed at the BL2 dogleg currently limit the peak current and the laser pulse energy stays around 100-150 µJ. To increase the laser intensity, rearrangement of the beam optics at the dogleg is under consideration to mitigate the CSR effects.

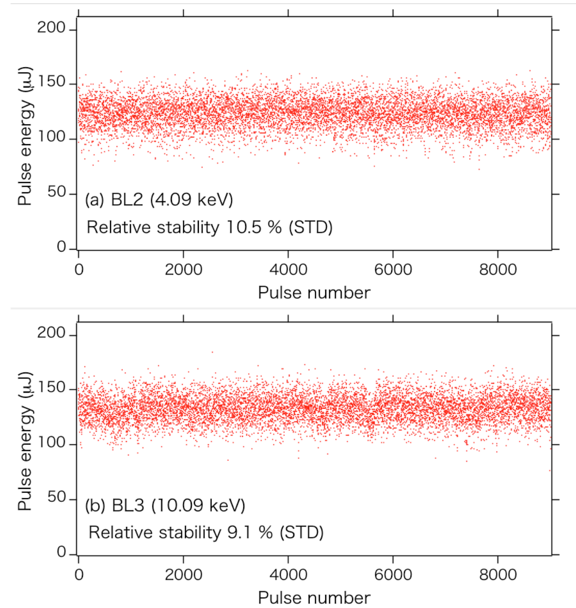

Figure 9: Stability of the photon pulse energy, (a) BL2 and (b) BL3. Red dots are single-shot resultsThe electron beam energy is 6.3 GeV for BL2 and 7.8 GeV for BL3. The undulator K-values are 2.85 and 2.1 for BL2 and BL3 respectively.

REFERENCES

[1] T. Hara et al., in Proceedings of FEL2014, Basel, August 2014, 71 (2014).
[2] T. Ishikawa et al., Nat. Photon. 6, 540 (2010).
[3] J. H. Han, H.S. Kang and I. S. Ko, in Proceedings of IPAC2012, New Orleans, May 2012, 1735 (2012).
[4] S. Reiche, in Proceedings of FEL2011, Shanghai, August 2011, 223 (2011).
[5] T. Hara et al., Phys. Rev. ST Accel. Beams 12, 080706 (2013).
[6] H. Tanaka, et al., to be published in Synchrotron Radiation News.
[7] T. Hara, K. Togawa and H. Tanaka, in Proceedings of FEL2010, Malmö, August 2010, 111 (2010).
[8] R. Talman, Phys. Rev. Lett. 56, 1429 (1986).
[9] B. E. Carlsten and T. O. Raubenheimer, Phys. Rev. E 51, 1453 (1995).
[10] M. Dohlus and T. Limberg, Nucl. Instr. and Meth. A 393, 494 (1997).
[11] E. L. Saldin, E. A. Schneidmiller and M. V. Yurkov, Nucl. Instr. and Meth. A 398, 373 (1997).
[12] D. Douglas, Thomas Jefferson National Accelerator Facility JLAB-TN-98-012 (1998).
[13] S. Di Mitri, M. Cornacchia and S. Spampinati, Phys. Rev. Lett. 110, 014801 (2013).
[14] E. Ego et al., Nucl. Instrum. Methods {¥bf A795}, 381 (2015).

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