Pulse-by-pulse multi-beamline operation of SACLA

X-ray Free Electron Lasers (XFELs) have distinctive characteristics such as high peak intensity, short pulse duration and coherence. Since XFELs require a high-brightness electron beam for lasing, a linear accelerator is used as an electron beam driver. Therefore, the electron beam is generally provided to only one beamline at the same time. In order to improve the usability and efficiency of XFEL facilities and satisfy the increasing demand for user experiments, the distribution of the electron beam to multiple beamlines has become an important issue.

SPring-8 Angstrom Compact free-electron LAser (SACLA) has been open to user experiments since 2012 [1]. Currently two XFEL beamlines (**BL2** and **BL3**) and one EUV FEL beamline (**BL1**) are in operation. BL1 is driven by the SCSS+ accelerator and independently operated from XFEL beamlines. In 2015, a switchyard composed of a kicker magnet and a DC septum magnet was installed at the end of the linear accelerator of SACLA. The switchyard can distribute 60 Hz electron bunches from pulse to pulse in three directions corresponding to the two XFEL beamlines and an electron beam injection line to the SPring-8 storage ring [2]. Figure 1 is a schematic of the current SACLA facility.

Since the stability of the electron beam orbit inside undulators is critically important for XFELs to ensure interaction between electrons and photons, high stability and reproducibility are required for the switchyard, particularly for the kicker magnet. At the switchyard, the destination of the electron beam is determined by the kicker magnet, which deflects the beam by either 0° or ±0.5°. The deflected beam is further bent by the DC septum magnet (2.5°) as shown in Fig. 1. The deflection angle of the kicker magnet is made as small as possible to relax the stability requirement for the pulsed power supply. The pulsed power supply employs PWM (pulse width modulation) regulation using eight FETs connected in parallel and it generates bipolar trapezoidal current waveforms with arbitrary amplitudes to cover various beam energies. Figure 2 shows the pulse-to-pulse stability of the kicker magnetic fields measured by a gated Nuclear Magnetic Resonance (NMR) probe. The typical peak-to-peak stability is 1×10^{-5} except for a slow drift, which can be corrected by electron beam orbit feedback.

In the multi-beamline operation, several user experiments are performed in parallel. Consequently, the wavelengths of the XFEL may be different between

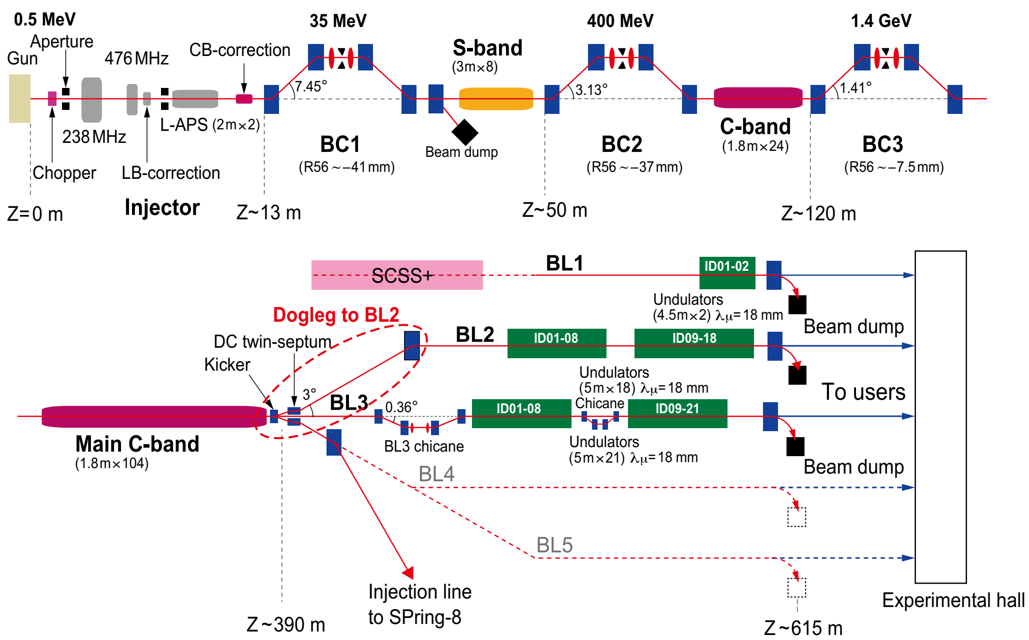

Fig. 1. Schematic of the current SACLA facility.

the experiments. In this case, it is necessary to change the electron beam energy of each beamline. At SACLA, the multi-energy operation of the linear accelerator has been successfully achieved, in which the beam energies of the electron bunches are controlled by changing the repetition rate of accelerator tubes [3].

The first multi-beamline operation of SACLA was demonstrated in January 2015. In the demonstration, 30 Hz electron bunches were alternately sent to the two beamlines, BL2 and BL3 [2]. Figure 3 shows the laser pulse energies measured at the two beamlines. Although stable lasing was successfully obtained at both beamlines, the peak current of the electron bunches was limited to 2 kA, as compared with 10–15 kA currently used for the nominal operation of BL3. The limitation of the peak current is due to CSR (coherent synchrotron radiation) at the dogleg in the electron beam transport line to BL2 (Fig. 1). When the electron bunch passes through a bending magnet, the beam energy is modulated inside the bunch owing to CSR. Then the emittance is degraded and the beam orbit becomes unstable for high-peak current bunches. Since SACLA BL2 has been operated with low peak currents to avoid the effects of CSR, the pulse energy has remained around 150 μJ, which is about a quarter of that of BL3 in the nominal operation.

To mitigate the effects of CSR, the electron beam optics of the BL2 dogleg transport line is planned to be rearranged in January 2017, in which symmetric optics based on a DBA (double bend achromatic) lattice is employed. In the new lattice, the deflection angles of all bending magnets are made the same (1.5°) to cancel out the effects of CSR between the bending magnets. Multi-beamline operation with the full laser performance of SACLA will be obtained after the lattice modification.

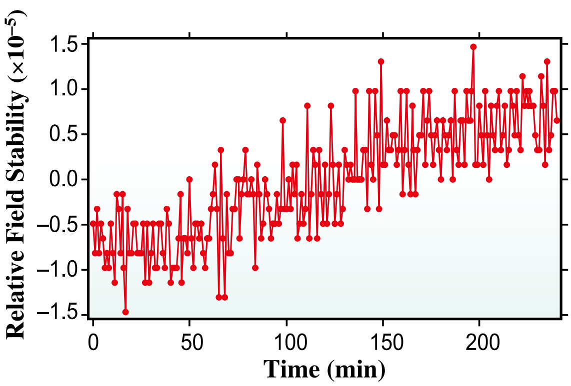

Fig. 2. Stability of the kicker magnetic fields.

The switchyard of SACLA is used not only for the multi-beamline operation of the XFEL but also for beam injection to the upgraded SPring-8 storage ring [4]. For the beam injection, the bunch length should also be controlled in addition to the beam energy from pulse to pulse, and the beam injection occurs at an arbitrary timing for top-up injection. To satisfy these requirements, the development of a new low level RF and timing system is under way. The beam injection test of the SPring-8 storage ring is scheduled for 2018.

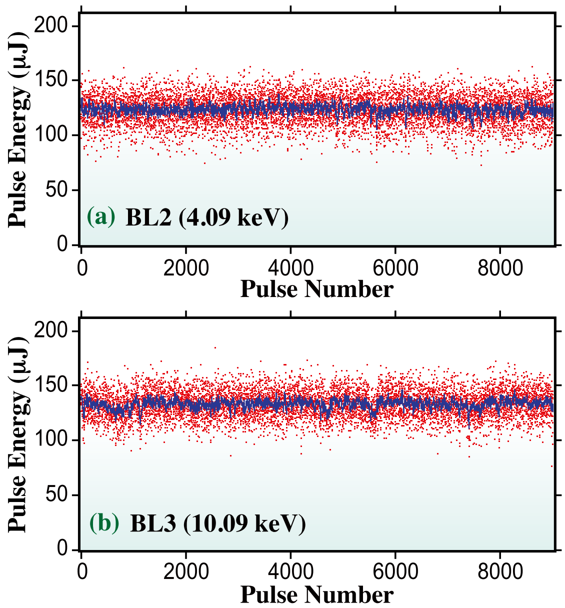

Fig. 3. XFEL pulse energies measured at (a) BL2 and (b) BL3 in multi-beamline operation. Red dots are single-shot data and blue lines are averaged values over 15 shots. The electron beam energies were 6.3 GeV and 7.8 GeV for BL2 and BL3, respectively.

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References

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