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SUPRESSION OF THE CSR EFFECTS AT A DOGLEG BEAM TRANSPORT USING DBA LATTICE

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Abstract

Multi-beamline operation is an important issue of linear accelerator based XFELs to improve usability and efficiency of a facility. At SACLA, the multi-beamline operation had been tested since 2015 using two XFEL beamlines, BL2 and BL3. But the CSR effects at a 3-degree dogleg beam transport of BL2 caused projected emittance growth and instability of the electron beam orbit due to a high peak current of 10 kA and short bunch duration of SACLA. Consequently, stable lasing was obtained only for elongated electron bunches with low peak-currents below 3 kA. To suppress the CSR effects, the beam optics of the BL2 dogleg was replaced to that based on two DBA structures. In the new beam optics, the transverse effects of CSR are cancelled out between four bending magnets. To avoid the bunch length change, the electron beam passes an off-center orbit at the quadrupole magnets of DBA. After the modification of the beam optics, stable lasing has been successfully obtained with 10-kA electron bunches. The parallel operation of the two beamlines will be started in autumn 2017 for user experiments.

INTRODUCTION

To meet the increasing demands from XFEL (X-ray Free-Electron Laser) users, the parallel operation of multiple beamlines is an important issue for improving the usability and efficiency of a facility [1].

Figure 1 is a schematic layout of SACLA (SPring-8 Angstrom Compact free-electron LAser) [2]. The undulator hall of SACLA can accommodate up to five undulator beamlines, and three of them have been installed so far. BL1 is a soft x-ray FEL beamline driven by a dedicated linear accelerator, SCSS+, which was originally build as a prototype of SACLA [3, 4]. BL2 and BL3 are XFEL

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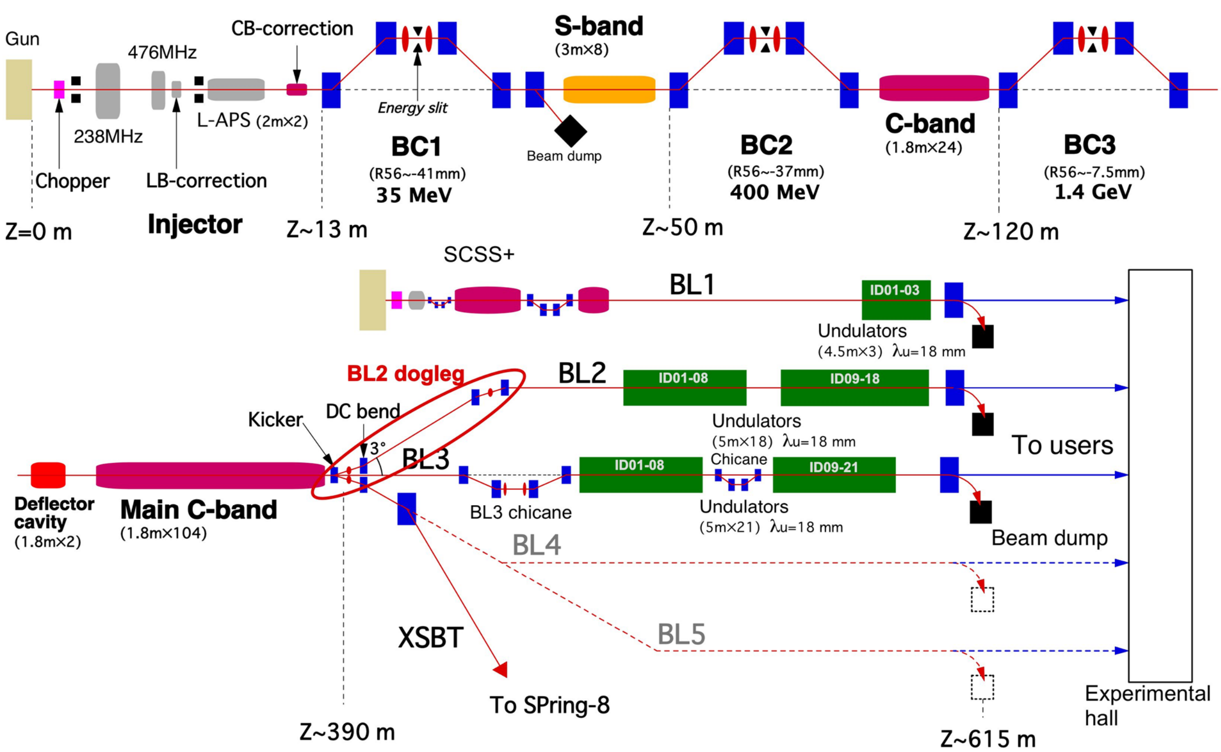

Figure 1: Schematic layout of SACLA.

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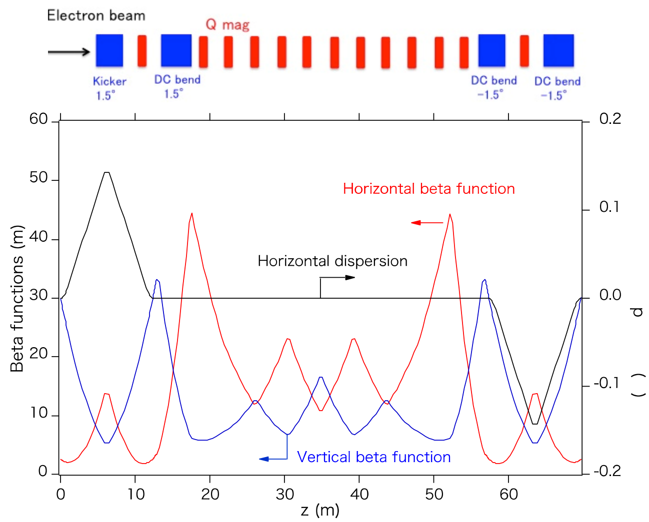

Figure 2: Magnet configuration (up) and beam optics functions (bottom) of the BL2 dogleg beam transport.

beamlines and a kicker magnet at the end of the SACLA linear accelerator switches the beamlines. The parallel operation of the two XFEL beamlines had been tested since 2015. However, the peak current of the electron beam was limited to below 3 kA due to the effects of CSR (Coherent Synchrotron Radiation) at a 3-degree dogleg electron beam transport to BL2 [1].

In order to suppress the CSR effects at the BL2 dogleg, the electron beam optics of the dogleg was changed to a new lattice based on DBA (Double Bend Achromat) structures. In this paper, the suppression of the CSR effects at the dogleg and the multi-beamline operation of SACLA are reported.

NEW BEAM OPTICS OF BL2 DOGLEG

Figure 2 shows the magnet configuration and beam optics functions of the new BL2 dogleg. Two DBA structures are placed at the entrance and exit of the dogleg to deflect the electron beam by 3 degrees. All four bending magnets, including a kicker magnet, are made identical with a deflection angle of 1.5 degrees. To suppress transverse CSR effects on the electron beam, such as projected emittance growth and orbit instability, the betatron phase advance between the two DBA is set to π [5, 6].

For the cancellation of the CSR effects, the longitudinal electron bunch profile should be the same at the four bending magnets. For the electron bunches used for the daily operation of SACLA having a peak current of more than 10 kA with 10~20 fs duration (FWHM), R_{56} of the dogleg, which is about 200 μm, is not negligible. In order to make R_{56} zero, the electron beam orbit is off-centered at the quadrupole magnets of the DBA structures.

Figure 3 shows a horizontal phase space distribution of the electron bunch after the dogleg calculated by ELEGANT [7]. A 10 kA-10 fs (FWHM) Gaussian bunch with 0.8 mm-mrad initial normalized emittance is assumed for figure 3. With a former optics of the dogleg, the horizon

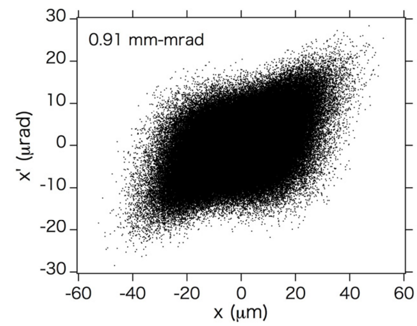

Figure 3: Horizontal phase space distribution of the electron bunch at the end of the BL2 dogleg. The initial conditions of the electron bunch are 8 GeV, 10 kA, 10 fs (FWHM) and 0.8 mm-mrad.

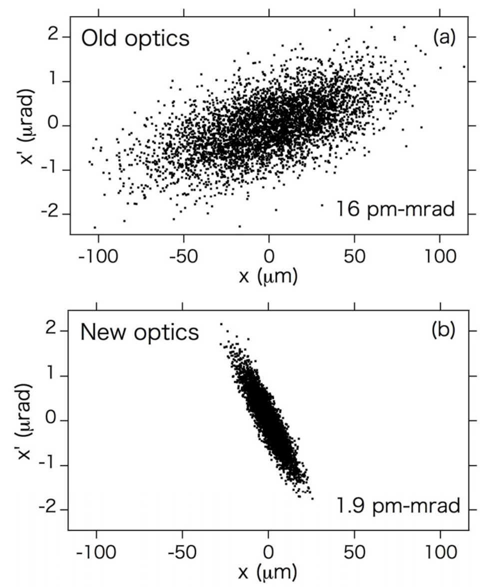

Figure 4: Stability of the horizontal electron beam orbit measured after the BL2 dogleg, before (a) and after (b) the replacement of the beam optics.

tal beam emittance becomes 8 mm-mrad after the dogleg, while the emittance of the new optics is 0.9 mm-mrad.

Since the deflection angle of the kicker magnet becomes three times larger in the new beam optics, the development of a pulsed power supply was a challenge [1]. By using SiC MOSFETs as switching elements, the new power supply achieves a targeted stability of 10 ppm (full width), which is small enough compared with an intrinsic orbit stability of SACLA [8] (see figure 4).

The beam optics of the BL2 dogleg was replaced in January 2017. Figure 4 is a comparison of the beam orbit stability before and after the replacement. The horizontal positions of the electron beam after the BL2 dogleg are measured and plotted in the phase space. The peak current of the electron beam is about 10 kA. From figure 4, the horizontal orbit stability is improved by an order of magnitude and the CSR effects are successfully cancelled with the new beam optics. The high peak current bunches are now stably transported to BL2 without serious emittance growth.

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MULTI-BEAMLINE OPERATION

Figure 5 shows the XFEL output in the multi-beamline operation. The repetition of the electron beam is 60 Hz and the electron bunches are alternately deflected to BL2 and BL3 by the kicker magnet. The laser pulse energies are increased by 2~3 times compared with those before the optics replacement due to the higher peak currents.

Since spectral tunability is one of the important features of FEL light sources, it should be maintained also for the multi-beamline operation. In figure 5, the beam energy is changed for BL2 and BL3 in addition to the undulator K-values. By running twenty C-band accelerating structures at 30 Hz, which is half of the beam repetition, the electron bunches are alternately accelerated to 6.5 GeV and 7.8 GeV [9]. Then the kicker magnet deflects the lower energy bunches to BL2 and the higher energy bunches to BL3. Together with the K-values, the difference of the photon energies between the two beamlines reaches a factor of two, and wide spectral tunability of XFEL is ensured for the multi-beamline operation.

When operating the two beamlines in parallel, the optimum condition of the electron bunch compression with respect to the laser output might slightly differ for the two beamlines. At SACLA, this is mainly due to the different R_{56} of BL2 and BL3. As mentioned previously, R_{56} of the BL2 dogleg is adjusted to zero to suppress the CSR effects, while a chicane, whose R_{56} is about -800 µm, is installed in front of the BL3 undulators to measure the final beam energy and remove dark currents from the C-band accelerator.

Figure 6 shows the laser pulse energies of BL2 and BL3 as a function of CSR monitor signals installed at BC3 [10]. The optimum condition of the bunch compression is different for the two beamlines. At SACLA, the electron bunch compression parameters, namely RF phases, can be changed from bunch to bunch to obtain the maximum laser pulse energy simultaneously at both beamlines.

SUMMARY

The new beam optics of the BL2 dogleg beam transport based on two DBA structures successfully suppresses the CSR effects. As a result, the laser pulse energy of BL2 is increased by a factor of 2~3 due to the higher peak current of the electron bunches.

In the multi-beamline operation of SACLA, the beam energy and the bunch compression parameters can be controlled from bunch to bunch and independently optimized for the two beamlines. Thus, the laser pulse energies can be maximized for the two beamlines and wide spectral tunability of XFEL is maintained.

The multi-beamline operation will be open to users in Autumn 2017, which expands the opportunity of user experiments.

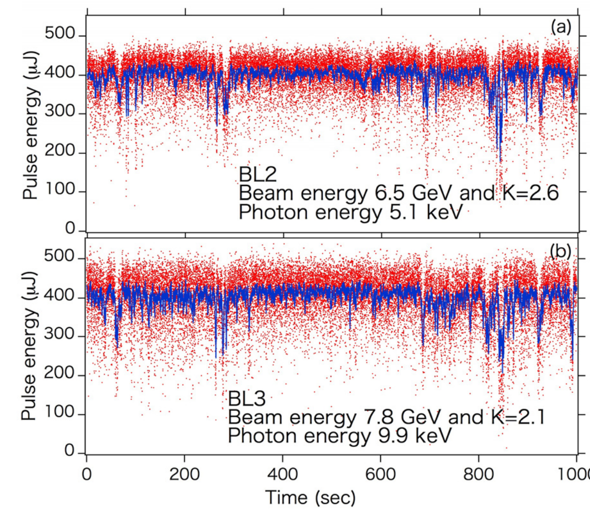

Figure 5: XFEL pulse energies obtained in the multi-beamline operation, (a) BL2 and (b) BL3. Red dots represent single-shot results and blue lines show averaged values over one second. The bunch repetition is 60 Hz. The electron beam energies and K-values are 6.5 GeV and 2.6 for BL2, and 7.8 GeV and 2.1 for BL3.

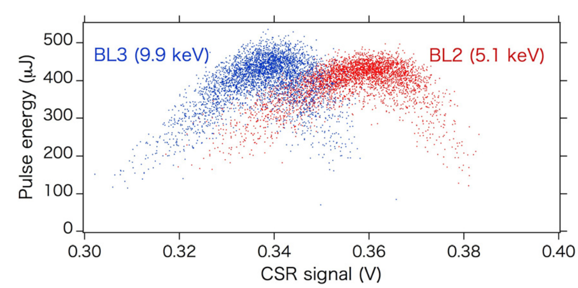

Figure 6: XFEL pulse energies of BL2 and BL3 plotted as a function of the CSR signal of BC3. The beam energies of BL2 and BL3 are 6.5 GeV and 7.8 GeV. Red and blue dots represent the pulses of BL2 and BL3, respectively.

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