Suppression of CSR effects at the dogleg beam transport of SACLA

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The parallel operation of multiple XFEL beamlines is an important issue of improving the efficiency and usability of XFEL facilities. After the installation of a second undulator beamline (BL2) at SACLA, pulse-by-pulse switching between two beamlines was tested using kicker and DC twin-septum magnets. Since the electron beam was deflected twice by 3 degrees in a dogleg beam transport to BL2, stable lasing was obtained only for long electron bunches with a low peak-current below 3 kA due to CSR effects. Recently we have changed the beam optics of the dogleg based on a DBA lattice to cancel out the transverse CSR effects between the bending magnets. As a result, full XFEL performance of SACLA is now obtained at BL2 with short electron bunches, whose length is about 20 fs with a peak current more than 10 kA. In this paper, the suppression of the CSR effects using two DBA structures at the SACLA BL2 dogleg beam transport is presented.

Keywords: X-ray FEL, linear accelerator, Coherent synchrotron radiation.

1. Introduction

Multi-beamline operation is an important issue to increase the opportunity of user experiments at XFEL facilities [1]. Since XFELs require dense electron beams with short bunch duration and a high peak current, CSR (Coherent Synchrotron Radiation) effects at bending magnets of a beam transport become a serious problem in the multi-beamline operation [2, 3].

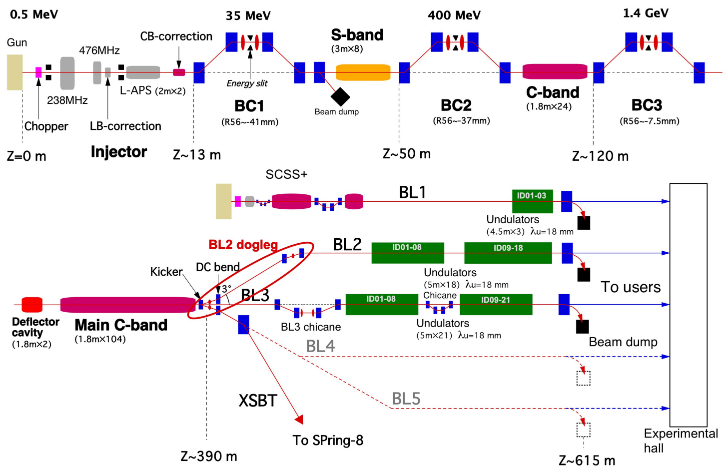

Fig. 1. Schematic of SACLA facility.

SACLA (SPring-8 Angstrom Compact free-electron LAser) uses the electron bunches with a peak current more than 10 kA and a bunch length less than 20 fs (FWHM) for daily operation. Figure 1 is a schematic of the SACLA facility [4]. The multi-beamline operation of SACLA was started in 2015 using two XFEL beamlines, BL2 and BL3. The electron beam was transported to BL2 through a 3-degree horizontal dogleg beam transport having asymmetric beam optics, which eases the stability requirement for a kicker magnet, but the beam orbit instability and emittance growth due to the CSR effects limited the peak current below 3 kA [1].

In order to mitigate the CSR effects, a new beam optics composed of two DBA (Double Bend Achromat) structures is introduced for the BL2 dogleg. The experimental results of suppression of the CSR effects are reported in this paper.

2. Suppression of CSR effects using a symmetric lattice based on DBA

Figure 2 shows the beam optics functions of the old and new BL2 dogleg lattices. In the new optics, all four bending magnet including the kicker magnet are made identical with a horizontal deflection angle of 1.5 degree [5]. The betatron phase advance between the bending magnets is designed to be π to cancel out the transverse kicks due to CSR at the end of the dogleg [6, 7]. In order to minimize the change of the longitudinal bunch profile, R_{56} is adjusted to zero by making the beam orbit off-centered at the quadrupole magnets of the DBA lattice.

Figure 3 shows the bunch distributions after the BL2 dogleg calculated for the old and new beam optics. In the new beam optics, the horizontal bunch center stays on the reference orbit and the projected emittance growth is small. Figures 4 and 5 are the measured orbit stabilities of the 10 kA electron beam. From Figure 4, the stability of the injection beam orbit to the BL2 undulators is significantly improved for the new beam optics due to the cancellation of the CSR effects. In Figure 5, the phase advance between the two DBA structures is intentionally changed between π and 2π. Since the condition of the cancellation is broken for a 2π phase advance, the fluctuation of the horizontal orbit increases after the dogleg (bottom figure of Figure 5).

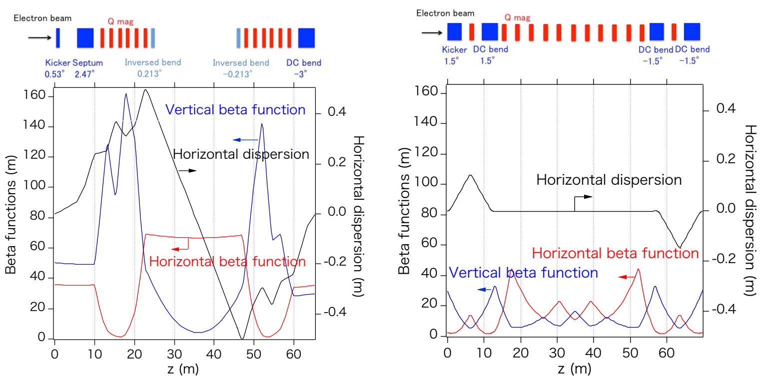

Fig. 2. Optics functions of old (left) and new (right) beam optics of the BL2 dogleg. The configuration of magnets is shown on top.

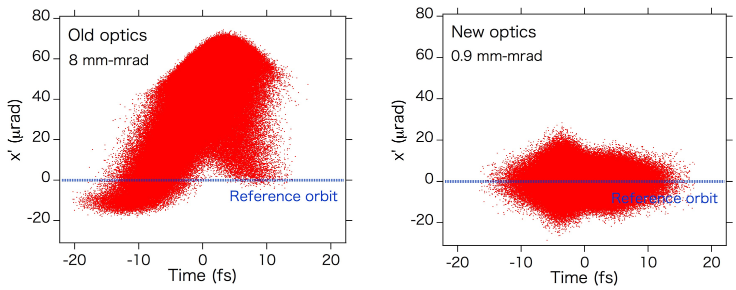

Fig. 3. Electron bunch distributions in a time and horizontal angle phase space after the BL2 dogleg calculated for old (left) and new (right) beam optics. A 10 kA-10 fs (FWHM) gaussian bunch with 0.8 mm-mrad normalized emittance is assumed as initial conditions.

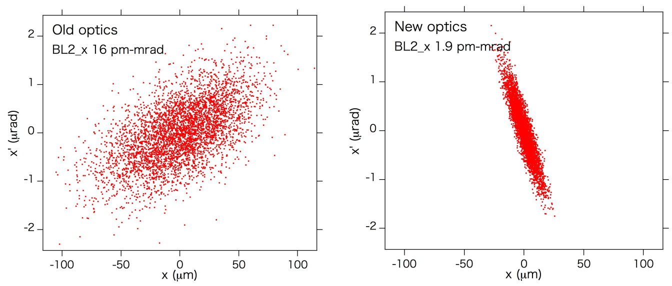

Fig. 4. Measured stabilities of the horizontal injection beam orbit to the BL2 undulators for old (left) and new (right) beam optics. The rms area in the phase space is indicated in each plot.

Fig. 5. Stabilities of the electron beam orbit measured with new beam optics along the accelerator, dogleg and BL2 undulators. The horizontal phase advance between the two DBA structure of the BL2 dogleg is set to π (top figure) and about 2π (bottom figure). In each figure, the upper and lower bar graphs correspond to horizontal and vertical orbit stabilities, and the bars indicate rms fluctuations of the beam positions measured by BPMs.

3. Summary

The new beam optics of the BL2 dogleg beam transport based on the two DBA structures successfully suppresses the transverse CSR effects. As a result, high peak current electron bunches of more than 10 kA are now stably transported to BL2 and the laser pulse energy increases from 150 μJ to 400 μJ. At SACLA, the multi-beamline operation has been offered to users since September 2017. Together with BL1, which is a soft x-ray FEL driven by an independent 800 MeV linear accelerator [8, 9], the parallel operation of the three FEL beamlines considerably expands the opportunity of user experiments.

References

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