LASER HEATER SYSTEM TEST AT PAL-XFEL ITF

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Abstract

Coherent x-ray photons are generated by a free electron laser (FEL). In PAL-XFEL, a photon beam with a 0.1 nm wavelength is generated from an electron bunch based on self-amplified spontaneous emission (SASE). An electron bunch with an uncorrelated energy spread in a level of 3 keV, which is generated from the photocathode RF gun, may be sensitive to longitudinal micro-bunching instability. The energy spread of an electron bunch can be increased to suppress the instability by Landau damping.

In order to control the uncorrelated energy spread, a laser heater system, which has a chicane with four dipoles chicane and a 0.5 m long undulator, was installed in the injector test facility (ITF) of PAL. In this paper, we introduce the parameters of the laser heater and heating effect on the electron bunch.

INTRODUCTION

An electron bunch with a peak current of 3 kA is required for hard x-ray FEL, such as PAL-XFEL [1]. An electron bunch with an uncorrelated energy spread of about 3 keV, which is generated from the photocathode RF gun, is sensitive to longitudinal micro-bunching instability. The instability may be induced by longitudinal space charge (LSC), linac wakefields and coherent synchrotron radiation (CSR) from the accelerating structures [2, 3]. A gain of the instability is susceptible to the energy spread and thus an increase of the energy spread of the electron bunch can suppress the instability by Landau damping without degrading the FEL performance [4].

A laser heater system is suggested to induce energy modulation to a bunch. The electron bunch interacts with an IR laser with a resonance condition in the undulator, $\lambda = \frac{\lambda_u}{2\gamma^2}(1+\frac{K^2}{2})$, where λ_u is the undualtor period, K is the undulator parameter and γ is the Lorentz factor. After installing a laser heater system at ITF of PAL in 2015, heating effect was studied in the longitudinal phase space by using an RF deflector and a spectrometer. In this paper, we introduce the parameters of the laser heater and heating effect with respect to undulator gap and IR laser parameters such as pulse energy, spot size and relative position to the electron beam.

LASER HEATER SYSTEM

The laser heater system, which was installed before an RF deflector, consists of four dipoles chicane, a 0.5m long unduatlor and YAG/OTR screens (Fig. 1). In order to measure the size and to align the position of the IR laser and electron bunch transversely, YAG/OTR screens [5] were located at both sides of the undulator.

As shown in Fig. 2, an IR laser with a pulse length of 10 ps (FWHM) was transported from the laser room to the tunnel of ITF. A photodiode which has a 1 ns rise time was used to check a rough temporal overlapping with the electron beam and then fine tuning was carried out by the laser delay line in the laser room while monitoring the increase of beam slice energy spread. The size and shape of the laser in the middle of the undulator were monitored by a CCD camera as a virtual camera on the optical table in the tunnel. The CCD camera was protected from damage of the laser using two IR filters which have an attenuation factor of 100 each. The laser was transversely matched with the electron beam in a level of 100 µm on both sides of the undulator by using two motorized mirrors. Figure 3 shows the images of the laser and electron beam at the entrance and exit of the undulator with a full gap. The electron beam was accelerated by two S-band 3m-long accelerating columns up to 135 MeV with 200 pC charge. The laser interaction with the beam generated 760 nm scale energy modulation along the bunch. The parameters of the laser heater and the electron beam are summarized in Table 1. Transverse emittance growth caused by the induced energy spread was negligible. The heating effect on the bunch was observed in the longitudinal phase space by using an RF deflector and a spectrometer.

Table 1: Parameters for Laser Heater of ITF

Parameter	**Symbol**	**Value**	**Unit**
Beam energy	E	135	MeV
IR laser wavelength	λ_L	760	nm
IR laser energy	E_L	< 250	µJ
IR laser pulse length (FWHM)	T_L	10	ps
Undulator parameter (gap 28.64 mm)	K	1.5	-
Undulator period	λ_u	50	mm
# of undulator periods	N_u	9	-
Bending angle of each dipole	θ	5.82	deg.
e-beam size at the entrance of und. (rms)	$\sigma_{x,y}$	221	µm
IR laser size at the entrance of und. (rms)	σ_L	229	µm

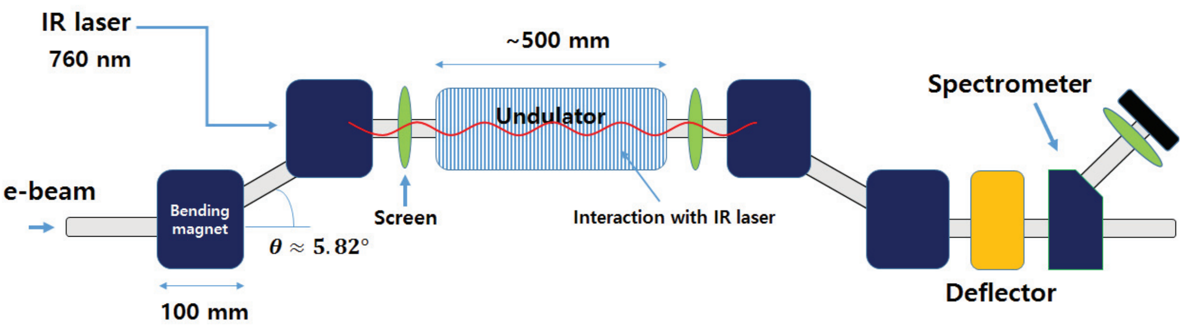


Figure 1: Layout of laser heater system at PAL-ITF.

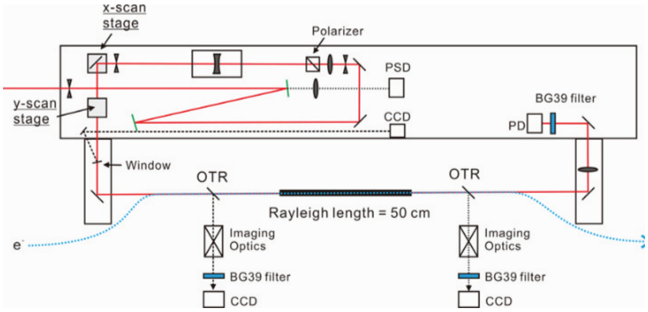
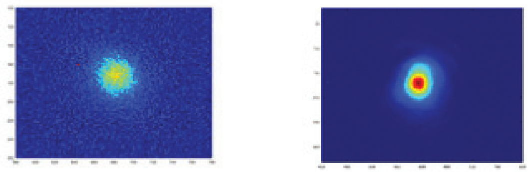
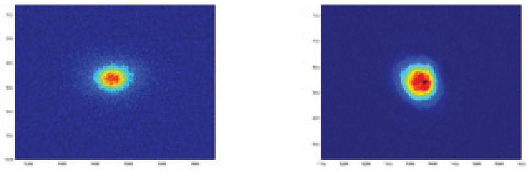


Figure 2: IR laser path on the optical table in the tunnel.



(a) $\sigma_{x,y} \approx 221$ μm.

(b) $\sigma_L \approx 229$ μm.



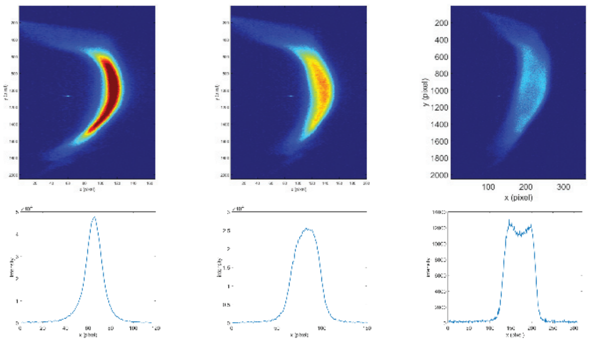
(c) $\sigma_{x,y} \approx 286$ μm.

(d) $\sigma_L \approx 248$ μm.

Figure 3: e-beam (left) and IR laser (right) images at the entrance (top) and exit (bottom) of the undulator.

HEATING EFFECT

Laser-electron beam interaction in the laser heater generates an uncorrelated energy spread along the bunch as the IR laser is aligned with the electron beam in space and time. The RF deflector and spectrometer were used to observe the longitudinal phase space distribution of the bunch. The deflector converts a time scale to the y-direction on the YAG screen which was located after the spectrometer and had a few keV energy resolution per pixel. Besides the spectrometer is a bending magnet which converts the beam energy to the x-direction. The laser rms size in the middle of the undulator was measured from the laser image on the CCD camera, which was located at the same distance from the splitter (see Fig. 2), and it was 204 μm. The electron beam rms size at the entrance of the undulator was 221 μm based on the YAG screen. The energy of the beam was 135 MeV. Laser pulse energy was adjusted in a range from 20 to 250 μJ. When the laser heater was off, an uncorrelated energy spread of the bunch in the core part (5% charge) was about 14.6 keV. The intrinsic energy spread of an electron bunch emitted from the RF gun is expected in the level of 3 keV from simulations. Both wakefield from the accelerating structures and incoherent synchrotron radiation from the spectrometer may induce the energy spread. Thus the energy spread of the bunch on the screen after the spectrometer might be increased about 10 keV. Figure 4 shows the induced energy spread of the bunch in the longitudinal phase space by the laser heating with the 204 μm laser size. The top of the bunch images corresponds to the head of the bunch. The induced energy spreads in the core part were 6.289 and 29.749 keV with 20 and 248 μJ laser energies respectively. The added energy spread was defined as Eq. (1) of Ref. [6] and averaged with five beam images.



(a) No heating (b) 20 μJ (c) 248 μJ

Figure 4: Induced energy spread in longitudinal phase space by laser heater for different IR pulse energy.

In Fig. 5, uncorrelated energy spread was induced as a function of undulator gap with a 248 μJ laser pulse. The red line is the theoretical value which assumes an ideal case of a laser, an electron bunch and magnets. The blue markers are the measurements which were obtained by subtracting the energy spread with no heating. The behavior of the measurements was similar with the theory. The resonant condition was achieved at a gap 28.8 mm and a calculated gap was 28.64 mm. The discrepancy in the gap may be caused by a slight miscalibration of the undulator gap.

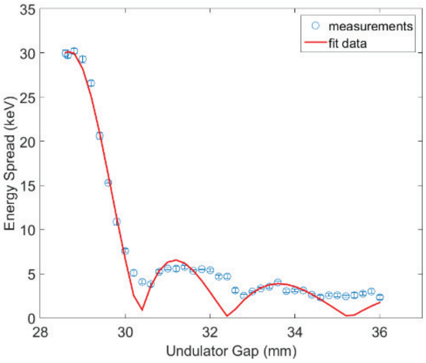
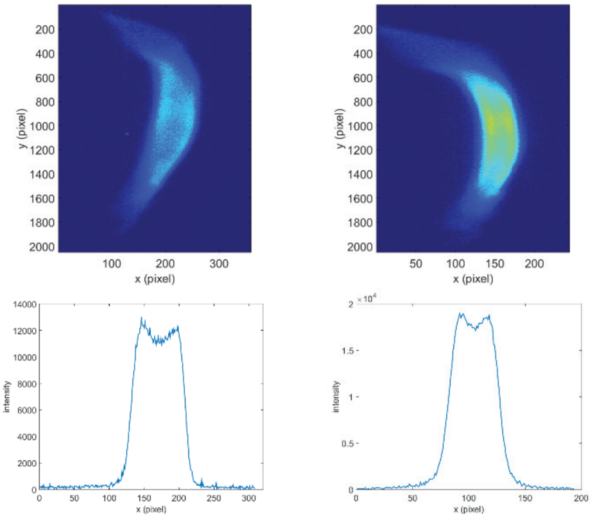


Figure 5: Induced energy spread as a function of the undulator gap with a 248 **µJ** laser pulse.

When the laser spot size is matched to the electron beam, the induced energy spread distribution is a Gaussian-like which is effective to suppress a micro-bunching instability. The larger laser size compared with the beam represents a double-horn energy distribution which is ineffective [4]. In the measurements at ITF, the double-horn pattern was observed with the larger laser size but the laser size matched the electron beam also indicated the double-horn energy distribution with a 248 µJ laser pulse (Fig. 6). It may come from collective effects in the injector.

In addition, induced energy spread was scanned as a function of relative laser position to the beam (Fig. 7). When the laser is apart from the centroid of the beam, heating effect on the central slice of the bunch is reduced.



(a) 204 µm (b) 496 µm

Figure 6: Bunch profiles with matched (a) and larger (b) laser size in longitudinal phase space.

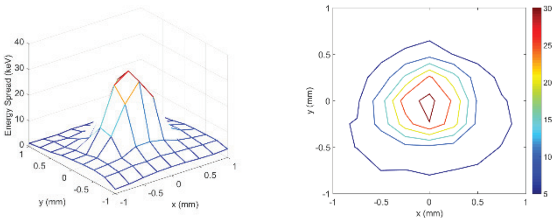


Figure 7: An induced energy spread map as a function of relative laser position to the electron beam.

CONCLUSION

The uncorrelated energy spread of an electron bunch was induced by the laser heater system at ITF. An instability driven by collective effects in an accelerator may degrade the quality of an electron bunch and thus the performance of PAL-XFEL. The induced energy spread was measured with variations in undulator gap and laser parameters such as laser pulse energy, size and spatial position relative to the electron beam.

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