Monitor for Microbunching Instability in X-ray Free Electron Laser

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Abstract

The microbunching instability is an important issue in an X-ray Free Electron Laser (XFEL) because the intensity of the FEL can be reduced significantly when the microbunching instability is generated. In the X-ray Free Electron Laser of the Pohang Accelerator Laboratory (PAL-XFEL), a visible CCD camera was installed in the existing coherent radiation monitor (CRM) for the bunch length monitoring. The measurement result shows that the CCD camera can be used as a direct monitor to diagnose the microbunching instability and can be used to optimize the FEL lasing in the PAL-XFEL.

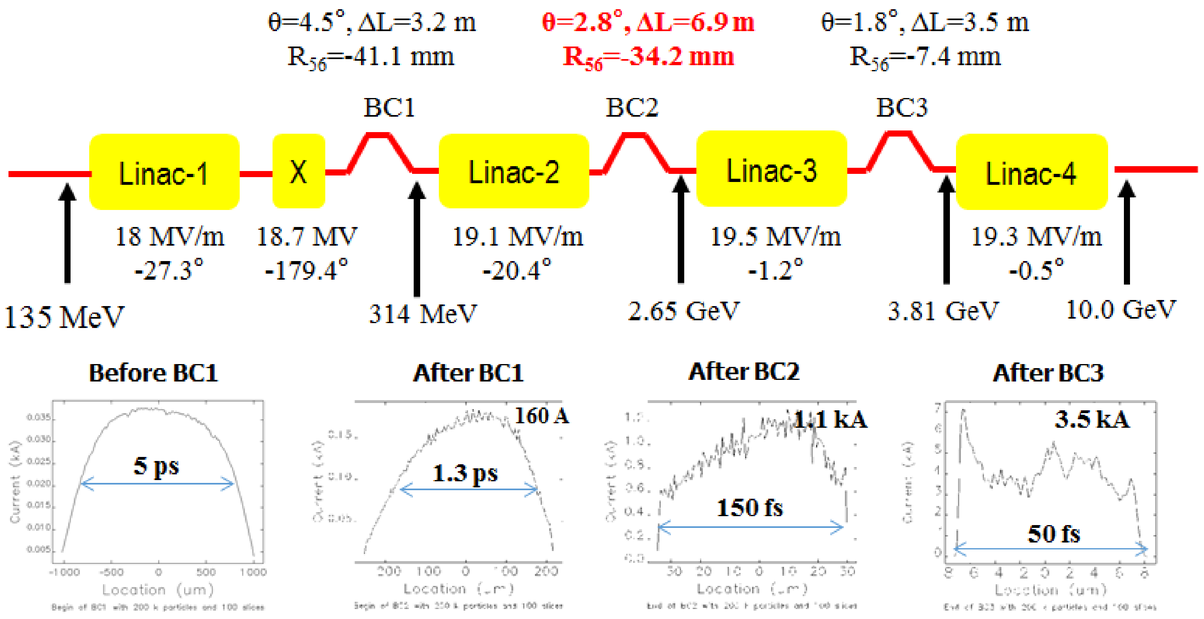
PAL-XFEL

Bird eyes view of PAL-XFEL

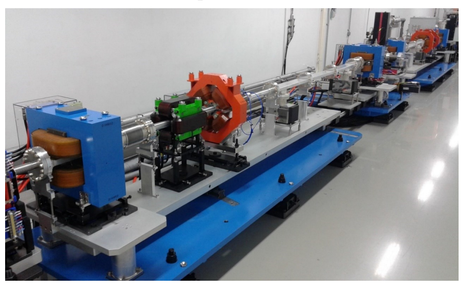
PAL-XFEL Parameters

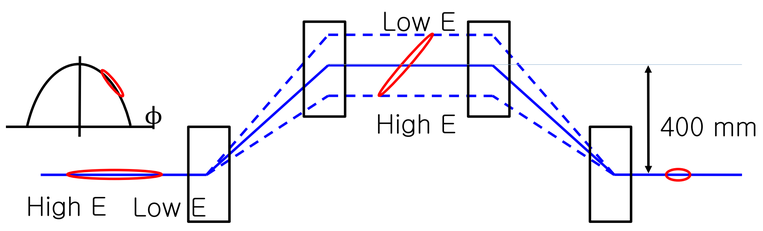
Parameters	Value
Beam Energy	10 GeV
Beam Charge	200 pC
Beam Emittance	0.5 mm-mrad
Rep. Rate	30 Hz (-> 60 Hz)
Current at Undulator	3.0 kA
Radiation Wavelength	0.1 ~ 0.7 nm

Electron Bunch Length

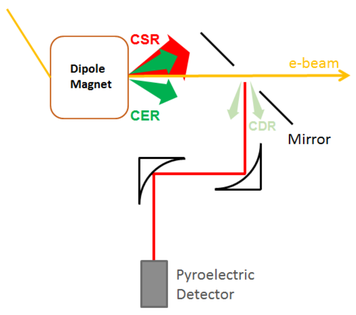


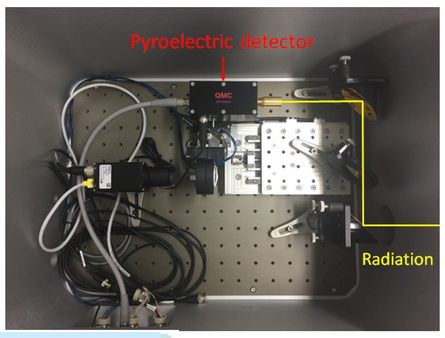
Bunch Compressor

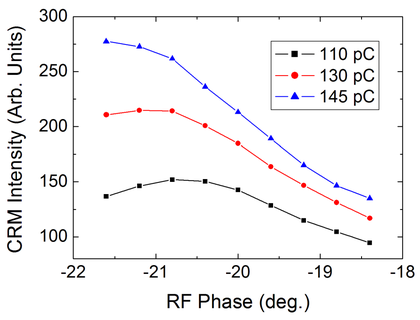


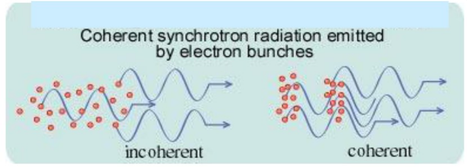


Coherent Radiation Monitor







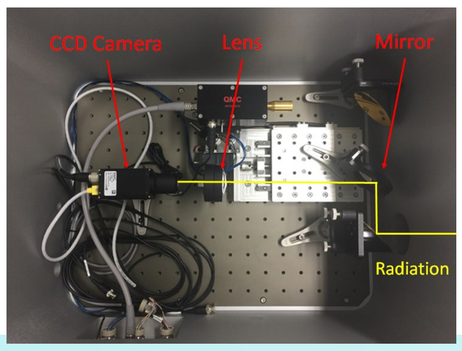


Radiation power $\propto \left(\sum_{j=1}^{N} E_j e^{i\phi_j}\right)^2 = \sum_{j=1}^{N} E_j^2 + \sum_{j=1}^{N}\sum_{\substack{k=1 \\ j\neq k}}^{N} E_j E_k^* e^{i(\phi_j-\phi_k)}$

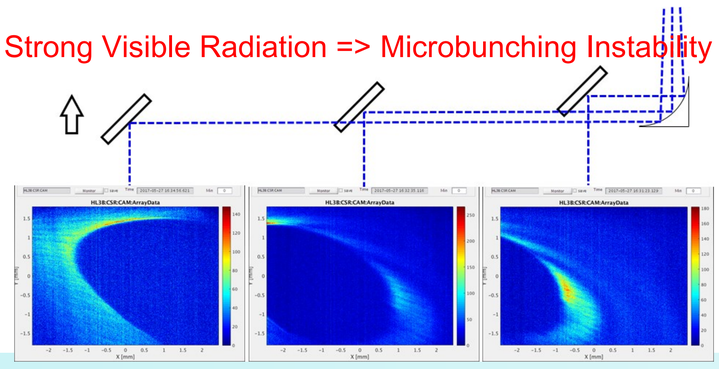
If $\phi_j \approx \phi_k \; \forall \, j$ then the 2nd term >> 1st term as there are N^2 of them and results in coherent emission.

Pyro Detector Range: 0.1 ~ 20 THz
Bunch Length = 30 fs (33 Thz) = 9 um
Visible Wavelength: 400 ~ 700 nm

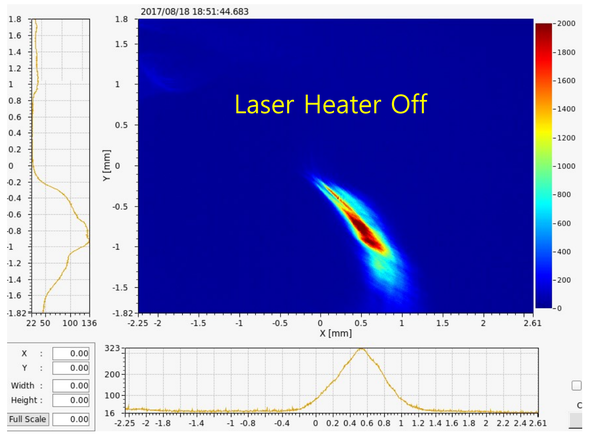
CCD Camera Setup

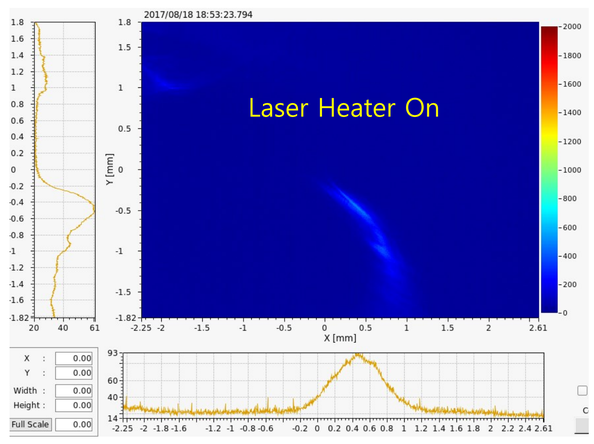


Strong Visible Radiation => Microbunching Instability

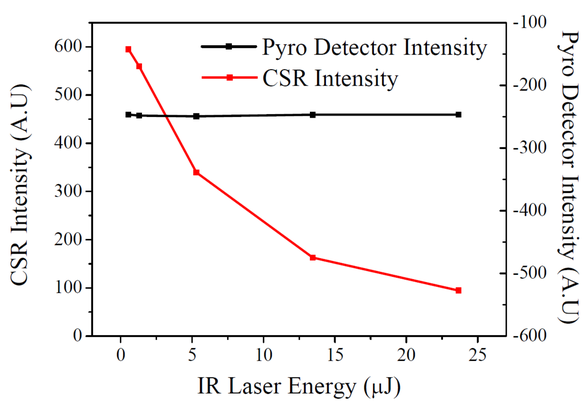


CSR Intensity with Laser Heater

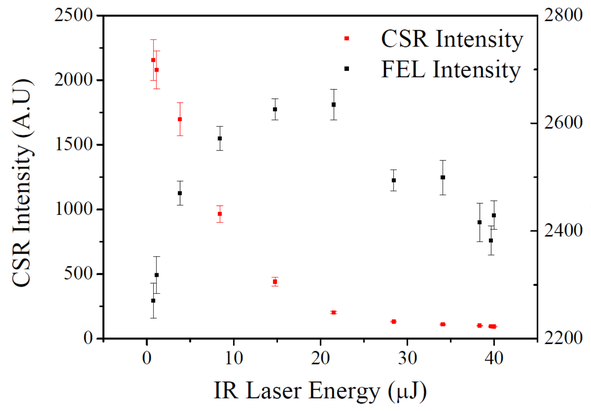




Laser Heater Optimization

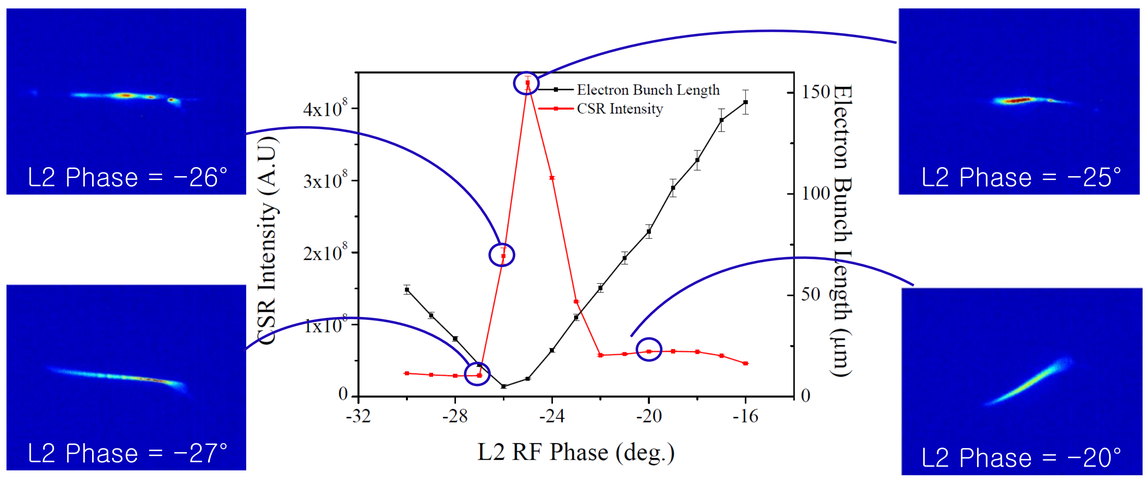


Measured intensity with the CSR monitor and the pyro detector as a function of the IR laser energy



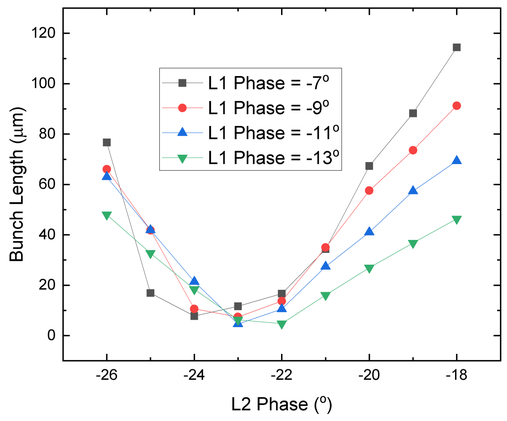
Measurement result of the CSR intensity and the FEL intensity as a function of the IR laser energy

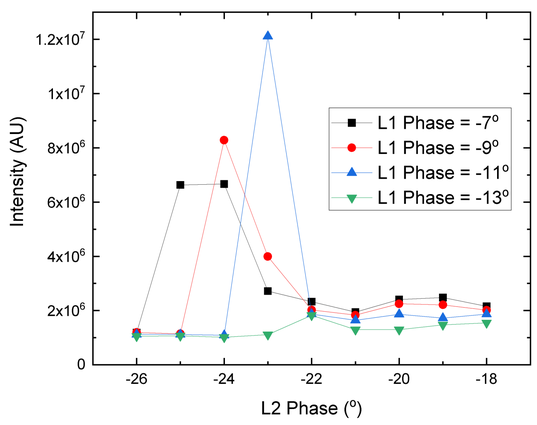
Linac #2 Phase Scan Results

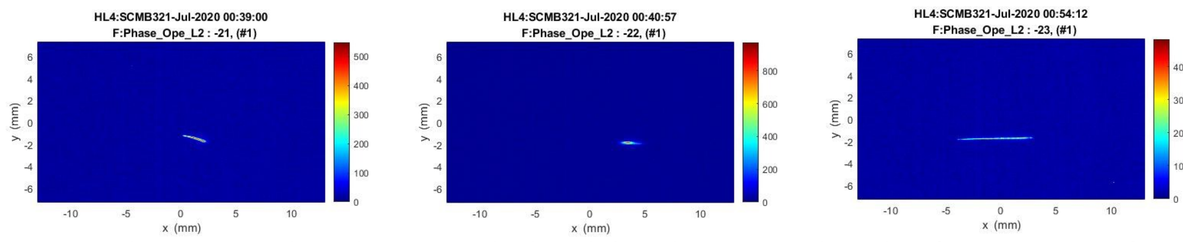


The CSR intensity and the bunch length as a function of the L2 RF phase. Transverse profiles after a deflecting cavity and a dipole magnet are shown as well. At L2 phase 26°, the energy spread was increased and the CSR intensity reduced down.

Linac #1 and Linac #2 Phase Scan Results







At L1 phase -13° and L2 phase -23°, the bunch length was very short, but fast increasing of energy spread from over compression suppressed the microbunching instability.

Summary

The microbunching instability was monitored by using a CCD camera in PAL-XFEL. We observed visible coherent radiation in a non-destructive way after the second bunch compressor and identified that the strong intensity of the visible light came from the microbunching instability. The coherent synchrotron radiation was sensitive to the laser pulse energy of the laser heater and it was used to find optimal laser energy to minimized the microbunching instability. The RF phase scan showed the microbunching instability was inversely proportional to the electron bunch length. However, even in the case of the short bunch length, the microbunching instability was suppressed when the energy spread of the electron beam was increased..

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