Start-End Simulations for the LCLS X-Ray Free-Electron Laser

S. Reiche[a], M. Borland[b], P. Emma[c], W. Fawley[d], C. Limborg[c], H.-D. Nuhn[c], C. Pellegrini[a]
[a]University of California, Los Angeles, CA 90095-1547, USA
[b]Argonne National Laboratory, Argonne, IL 60439, USA
[c]Stanford Linear Accelerator Laboratory, Stanford, CA 94309, USA
[d]Lawrence Berkeley National Laboratory, Berkeley, CA 94720, USA

The LCLS Free-Electron Lasers operates in the wavelength range of 1.5 - 15 Angstrom, using an electron beam with an energy between 4.5 and 14.5 GeV. The generation of the electron beam, the preservation of its brightness during acceleration and compression, and the amplification of the spontaneous radiation within the FEL can only be described by a consistent set of simulation codes.

We present the change in the FEL performance with respect to the LCLS design case, when various effects are included, altering the electron beam distribution and motion (e.g. wake fields, CSR, magnet misalignment or field errors of the undulator field). To distinguish the individual contribution of each effect, multiple start-end simulations are performed, including step by step additional effects and, thus, approaching a more and more realistic model of the LCLS FEL.

1. Introduction

Improvements of high brightness electron beam sources and the successful operation of Self-Amplifying Spontaneous Radiation Free-Electron Lasers (SASE FEL) down to a wavelength of 80 nm [1] are essential experimental results for a successful operation of proposed X-ray Free-Electron Lasers such as LCLS [2] and TESLA X-FEL [3]. These experiments have been modeled with start-end simulations. In the LCLS case, discussed here, we are using Parmela for the injector, Elegant for the main linac and Ginger and Genesis for the FEL. In this presentation, we study the influence of various effects on the FEL performance: coherent synchrotron radiation, wakefields in the linac and undulator, misalignment of linear accelerator and undulator components, and tolerance studies on linac jitters and undulator field errors.

2. CSR and Undulator Wakefields

The emission of coherent synchrotron radiation [4] in the bunch compressor and the energy change during the FEL process due to undulator wakefields [5] have the strongest impact on the FEL performance reducing the FEL output power by up 40%.

Simulation were done for a 50 fs subsection of the bunch in the central and head region of the bunch, deriving the particle distribution from the Elegant output. The results are shown in Fig. 1. The Genesis 1.3 results have a lower saturation power, because undulator wakefields were included. The calculated radiation spectra were in good agreement

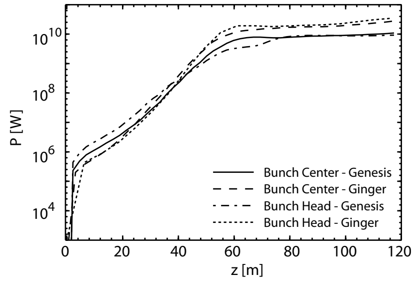

Figure 1. Radiation power along the undulator for a core and head region of the electron bunch. Undulator wakefields were only included in the Genesis simulations.

3. Beam Line Misalignment

For this study, transverse misalignments are added to all quadrupole magnets, accelerator structures, and beam position monitors (BPMs) with a Gaussian uncorrelated level of 300 microns rms. The emittance growth is effectively a head-to-tail varying centroid kick along the bunch length. Correction is accomplished by empirically varying the linac trajectory, using two pairs of steerers at the beginning of the linac, while minimizing the measured emittance at the end of the linac [6]. Final emittance levels are typically correctable to within ≈ 10% of their initial values.

4. Jitter Tolerances

We estimate the jitter tolerance by 200 independent runs with Parmela [7], Elegant and Genesis, where various beam line parameters such as rf phases and voltages has been varied. The resulting tolerances has been reported elsewhere [8]. The strongest impact on the FEL performance is the resulting jitter in the beam centroid position at the entrance of the undulator (see Fig. 2). It results in a strong fluctuation of the FEL output power.

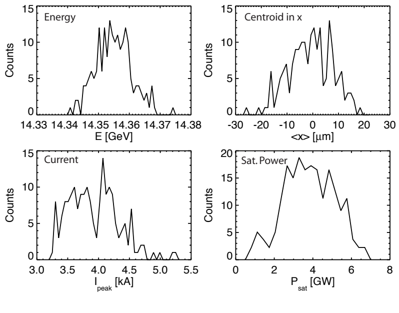

Figure 2. Jitter in the beam energy, beam centroid in x, current and saturation power for 200 random variations in beam line parameters.

5. Undulator Errors

For our study we include three sources of undulator errors: quadrupole misalignment, variation in the field strength of the undulator poles and misalignment of undulator modules. The tolerance of the BPM resolution for the beam-based alignment procedure [9]is 3 μm while it is 100 μm for the undulator modules. With the achievable precision in the magnetic field measurement the resulting degradation is less than 15%.

6. Conclusion

The simulation codes Parmela, Elegant, Ginger and Genesis have been successfully used for start-end simulations of the LCLS X-ray Free-Electron Laser. Including effects such as misalignment and beam jitter, the results yield tolerances of the machine alignment and stability. However a degradation of up to 60% and a fluctuation in the FEL output power of more than 25% cannot be removed.

REFERENCES

1. V. Ayvazyan *et al.*, Phys. Ref. Lett. **88** (2002) 104802
2. *Linac Coherent Light Source (LCLS)*, SLAC-R-521, UC-414 (1998)
3. TESLA-FEL 2001-05, Deutsches Elektronen Synchrotron, Hamburg, Germany (2001)
4. Y.S. Derbenev *et al.* TESLA-FEL 95-05, DESY, Hamburg, Germany (1995)
5. S. Reiche and H. Schlarb, Nucl. Inst. & Meth. **A445** (2000) 155
6. J. T. Seeman et al., 15th International Conference on High-Energy Accelerators, Hamburg, Germany, July 1992.
7. C. Limborg *et al.*, Proc. of the 25th Free-Electron Laser Conference, Tsukuba, Japan, 2003
8. P. Emma, Proc. of the Start-end Workshop, Desy-Zeuthen, Germany, 2003
9. P. Emma, R. Carr, H.-D. Nuhn, Nucl. Inst. & Meth. **A 429** (1999) 407