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Impact on LCLS-II FEL performance from a sudden increase in charge at the cathode

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Abstract

This technical note details the impact on the 100 pC charge electron beam LCLS-II FEL performance from sudden increases in charge at the cathode. Start-to-end simulations are used to evaluate the FEL performance from sudden charge increases to 130 pC and 200 pC.

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1 Introduction

The XTES BCS damage limits are based on both analytic estimates of the optimal FEL performance as well as start-to-end (S2E) numerical particle simulations from the cathode through the undulator. This technical note addresses the possibility to either accidentally (through random fluctuations) or intentionally change the charge at the cathode, once at a given set point, and drive the FEL beyond the BCS damage limit before feedback integration times would trip off. We analyze this scenario for the optimal 100 pC electron beam charge set point in the cases where the charge instantaneously increases to 130 and 200 pC. The FEL performance, using the total pulse energy as the performance metric, is analyzed for each case by increasing the charge on the cathode and performing a S2E simulation given the nominal accelerator and undulator set point parameters without re-optimization or matching.

2 Electron beam properties

An accelerator parameter set point is established through S2E simulations for electron beam charges that span the expected operational space. These S2E simulations leverage a sophisticated multiobjective global optimization over a large number of accelerator parameters of the cathode-to-undulator performance as well as detailed taper optimizations in the undulator [1]. Figure 1 shows the longitudinal phase space of the 100 pC electron beam, as well as the slice parameters that are important for FEL lasing, at the entrance to the SXR undulator. The core of the electron beam is relatively flat, shows a small signature of microbunching instability driven energy modulations, and is preceded by a broad current spike of $I \sim 1.3$ kA. The current in the core of the beam is roughly $I \sim 800$ A while the normalized slice emittance is $\epsilon_{n,(x,y)} \sim 0.35$ mm-mrad and the rms slice energy spread is $\sigma_E \sim 450$ keV.

Figure 2 shows the results of tracking a 130 pC charge electron beam off the cathode using the 100 pC set point without re-optimizing lattice parameters. The electron beam exhibits additional curvature in the core as well as increased energy modulations from the microbunching instability. The leading current spike is compressed while the slice emittance and energy spread are increased relative to the 100 pC charge electron beam.

Figure 3 shows the results of tracking a 200 pC charge electron beam off the cathode using the 100 pC set point without re-optimizing the lattice parameters. The beam shows additional deterioration in the slice parameters important for FEL lasing relative to the nominal 100 pC electron beam slice parameters. A larger deviation in charge seems to indicate a further decline in electron beam quality.

3 FEL simulation results

The nominal 100 pC charge electron beam is used in high fidelity FEL taper optimizations to find the undulator taper profile that produces the most FEL energy. This taper profile is then used without modification to evaluate the FEL performance of the 130 and 200 pC charge electron beams discussed above. Figure 4 shows the gain curves for each of the charge

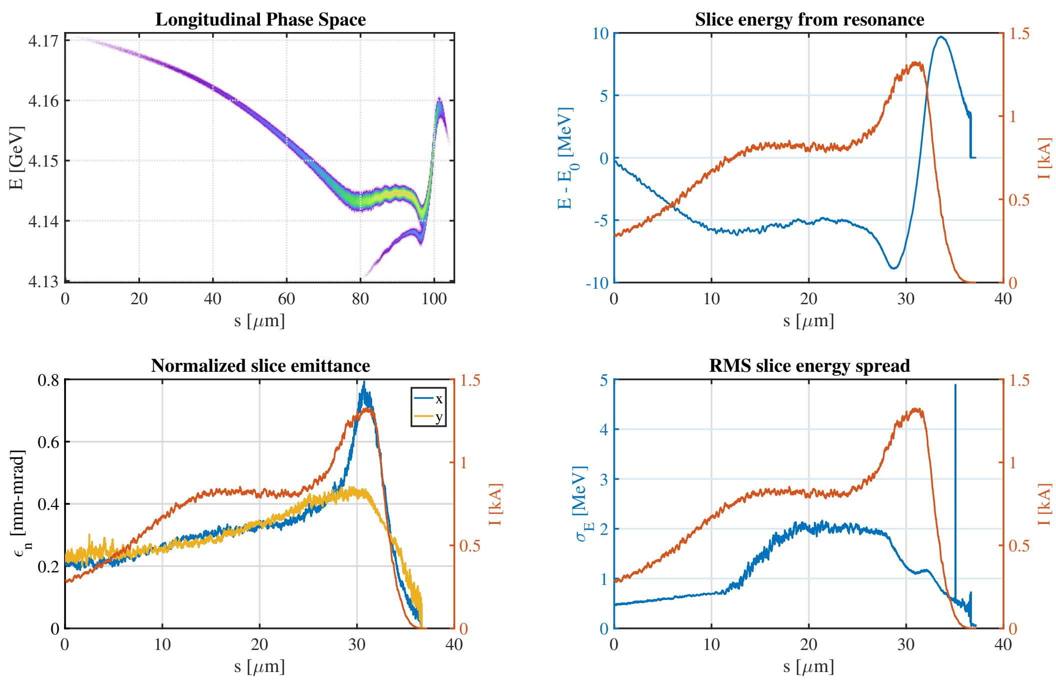

Figure 1: 100 pC electron beam properties. Top left: Longitudinal phase space. Top right: Current (red) and slice energy (blue). Bottom left: Current (red), slice emittance (blue - x, yellow - y). Bottom right: Current (red), rms slice energy spread (blue).

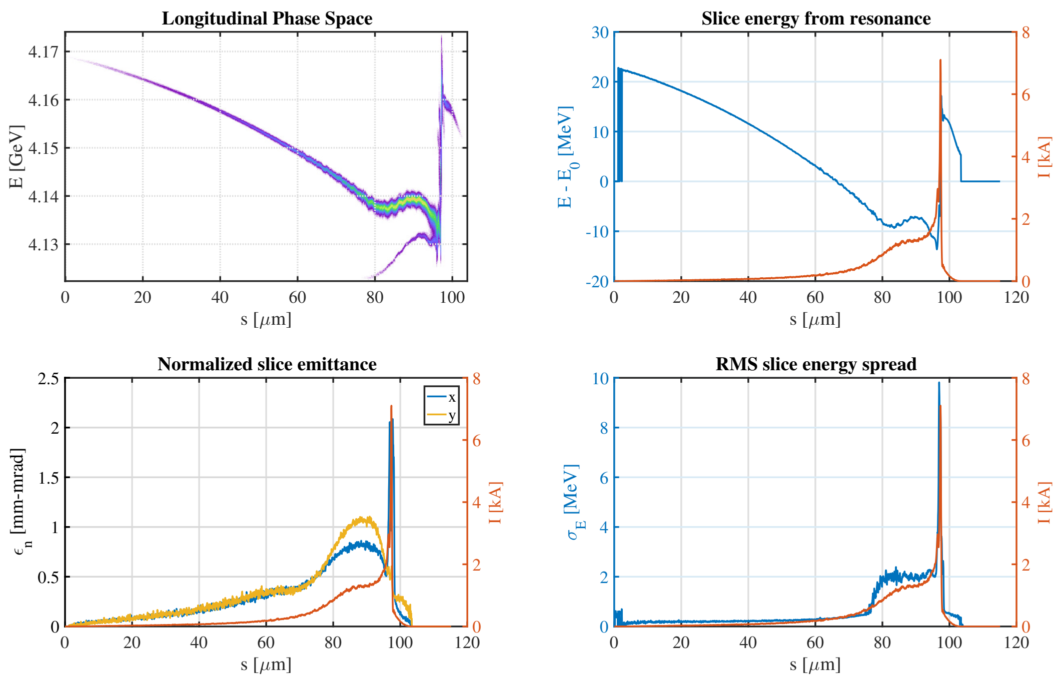

Figure 2: 130 pC electron beam properties. Top left: Longitudinal phase space. Top right: Current (red) and slice energy (blue). Bottom left: Current (red), slice emittance (blue - x, yellow - y). Bottom right: Current (red), rms slice energy spread (blue).

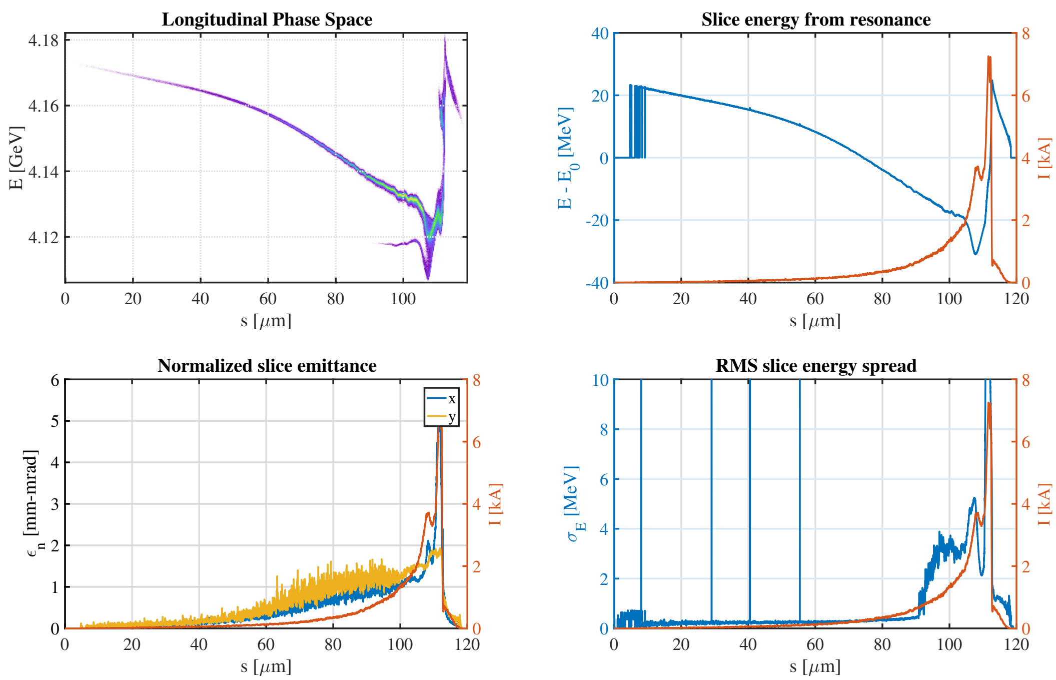

Figure 3: 130 pC electron beam properties. Top left: Longitudinal phase space. Top right: Current (red) and slice energy (blue). Bottom left: Current (red), slice emittance (blue - x, yellow - y). Bottom right: Current (red), rms slice energy spread (blue).

distributions when the SXR undulator is tuned to produce 260 eV photons. The 100 pC

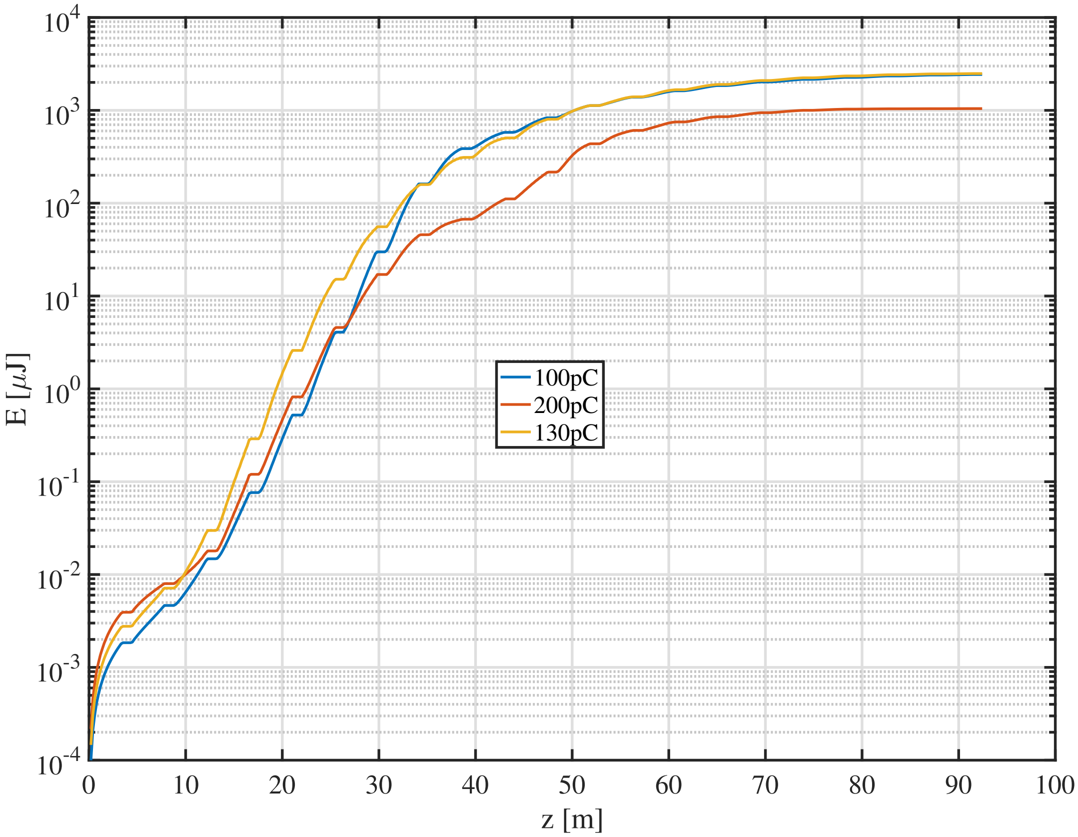

Figure 4: Energy gain curve for the three charge distributions mentioned above.

charge electron beam produces roughly 2.4 mJ of x-ray energy at the end of the undulator with an optimized taper. The 130 and 200 pC charge distributions produce 2.4 mJ and 1.0 mJ of pulse energy respectively with the same taper. The general trend indicates that the FEL performance suffers more drastically with a larger electron beam charge deviation at the cathode given one has found an optimal accelerator and undulator parameter set point. The FEL performance at the low end of the tuning range is typically the most forgiving with respect to non-ideal electron beam slice parameters. Therefore, we expect a further decrease in FEL performance from the 130 and 200 pC charge electron beams relative to the 100 pC charge electron beam set point at the higher end of the tuning range.

4 Conclusion

Start-to-end simulations were used to evaluate the change in FEL performance from sudden charge increases at the cathode from 100 pC to 130 pC and 200 pC. Detailed global optimizations of the accelerator and undulator were performed to find a nominal parameter set point and to establish an optimal FEL performance using the x-ray pulse energy as the performance metric. This set point was then used to evaluate the FEL performance at the low end of the tuning range in the SXR undulator assuming some mechanism that would instantaneously increase the charge off the cathode to either 130 pC or 200 pC. In both cases, the electron beam slice parameters important for FEL lasing were negatively impacted and the FEL performance suffered. The performance degradation should be more severe at the high end of the tuning range where the FEL is more sensitive to the electron beam slice parameters. Therefore, this limited study suggests that it would be difficult to find a scenario where the BCS damage limit will be exceeded from large charge fluctuations at the cathode.

References

[1] G. Marcus, J. Qiang, "LCLS-II SCRF start-to-end simulations and global optimization as of September 20", LCLS-II TN-17-04, 2017.