IMPROVING AND MAINTAINING FEL BEAM STABILITY OF THE LCLS*


Abstract

The beam stability of the Linac Coherent Light Source (LCLS) has seen many improvements over the years and has matured to a state where progress is slow and maintaining the best stability is becoming the main challenge. Single sources which are identified by various means contribute to only about 10 to 20% of the whole jitter power, meaning that their elimination gives only a small improvement of 5 to 10%. New sources need to be identified fast. Especially slow variations of a few seconds to minutes time scale are often hidden and partially corrected by feedback systems. A few episodes of increased jitter have shown the limitations of some of the feedback systems. Stability for all dimensions, transverse, longitudinal, and intensity are presented.

INTRODUCTION

The stability requirements for seeded beams and the improvements over many years are summarized in [1] and the references therein. Here we will discuss some of the newer developments: Soft x-ray seeding; new L1S SLEDsed setup; slow feedbacks; and jitter at optimized conditions.

SELF SEEDING

Soft X-Ray Self Seeding

Since most of the energy jitter in LCLS is already present after the linac region (L2), where the last energy spread for compression is introduced, the relative jitter is higher for soft x-rays, Fig. 1. It is about 0.08% at 5GeV (BC2 = bunch compressor) and three times lower 0.03% at 15 GeV. For soft x-rays the beam is decelerated down to 2.5 GeV so the relative jitter increases up to 0.16%.

If the FEL $\rho$-parameter were to scale similarly, the energy stability requirements for hard and soft x-rays would be the same, but $\rho$ does not scale as fast:

$$\rho \approx \frac{1}{4} \left( \frac{1}{2\pi^2} \frac{I_{pk}}{I_A} \frac{\lambda^2}{\beta_e \gamma} \right)^{2/3}$$

with $\lambda$ the undulator period, $K$ its strength, $\gamma$ the relative electron energy and $\beta_e$ the normalized emittance. The peak current $I_{pk}$ is typically lower at long wavelengths. This causes the jitter to be about three times the desired value and only a third of the pulses have significant seeding intensity [2] (Fig. 2).

Figure 1: Four-month history of energy jitter versus photon energy. Jitter decreases from 0.15% to 0.05% for soft x-rays and is around 0.04 % for hard x-rays. A special L3 phase setup of -15° reduces it further by about 20%. Energies between 2 and 5 keV are seldomly used, so the error bars are bigger.

Figure 2: Soft seeded intensity versus electron beam energy. Off energy beams do not seed, the jitter is with 0.082% more than 1.5 times the rms of the distribution (0.052% = $\rho/2$). The goal is half of the distribution rms.

Hard X-Ray Self Seeding

At hard x-ray energies the desired energy stability value of 0.020% is nearly achieved; it had to be only reduced by a factor of two since the initial commissioning time, see Fig. 3.

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The second change was found more accidentally. By adjusting the modulator HV timing to fine tune the jitter it was found that when it heavily cuts into the RF pulse the jitter is greatly reduced from $0.065^\circ$ to $0.035^\circ$. Explanations might be the timing of the unsteady reflection at the RF loads, or the softer slope reducing the load multi-pacting variations.

LIS SLED Pulse PAC Out(b), Forward(c), RMS*$1000$(m)

Figure 5: Special LIS SLED waveforms. The amplitude after the $180^\circ$ switch at $-1\,\mu$s is slowly ramped up with the phase and amplitude control (PAC, blue) giving a flatter integrated waveform after the SLED cavity. The forward pulse after the klystron (red) is additionally cut early by timing the modulator late. This causes the unsteady reflection in the RF load after the accelerator structure to fall near $-1\mu$s which reduces phase jitter.

The disadvantage of this setup is the higher sensitivity to modulator timing jitter, which was quite strong for about an hour each day in the last two weeks of April 2014, see Fig. 6. Luckily it just calmed down an hour before a seeded beam run (Fig. 7).

Figure 6: Short periods of increased amplitude (only) jitter of LIS caused the final beam energy jitter to increase 2-3 fold.
Figure 7: FEL photon intensity in mJ. The initial strong variations from 1.5 to 4 mJ were caused by L1S amplitude jitter. The problem disappeared an hour before the seeded setup of 20 min and following run with different taper setting and peak seed powers up to 1.5 mJ.

Other Energy Jitter Improvements
The early RF stations L0A and L0B got end-of-line clippers in the modulator, and L0B with SLED similar to L1S. L0A will follow soon. Slow variations (2 min) were observed with the peak current feedback for L1S phase chasing temperature oscillations in L0A. This was reduced adjusting the water regulation feedback and using both input and output phase measurements of the accelerating structure, although the output is very noisy.

High voltage jitter of 0.1% in the modulator creates RF jitter of 0.5° in phase and 0.17% in amplitude. At 90° the 0.5° phase jitter turns into 0.87% amplitude jitter, therefore the feedback stations in Li29 and Li30 are so visible in Fig. 4. By turning all 16 klystrons on and reducing the phase to ±25°, so there is only 1.5 klystrons overhead in the feedback, the sensitivity to phase changes is reduced by more than a factor of two from 0.87% to 0.37%.

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CONCLUSION
A factor of 1.5 in energy jitter reduction has been achieved, which is now nearly within tolerances for hard x-ray self-seeding, while for soft x-ray seeding another factor of two to three is necessary. Some approaches have been identified, which should get us about halfway there. FEL intensity correlation with transverse jitter has been used to improve the FEL performance. With second order fits sources can be identified at the optimum.

REFERENCES

02 Synchrotron Light Sources and FELs
A06 Free Electron Lasers