IMPROVING AND MAINTAINING FEL BEAM STABILITY OF THE LCLS*

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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 SLEDed 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 ρ-parameter were to scale similarly, the energy stability requirements for hard and soft x-rays would be the same, but ρ does not scale as fast:

$$\rho \approx \frac{1}{4}\left(\frac{1}{2\pi^2}\frac{I_{pk}}{I_A}\frac{\lambda_u^2}{\beta\varepsilon_N}\left(\frac{K}{\gamma}\right)^2\right)^{1/3}$$

with λ_u being the undulator period, K it's strength, γ the relative electron energy and ε_N 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).

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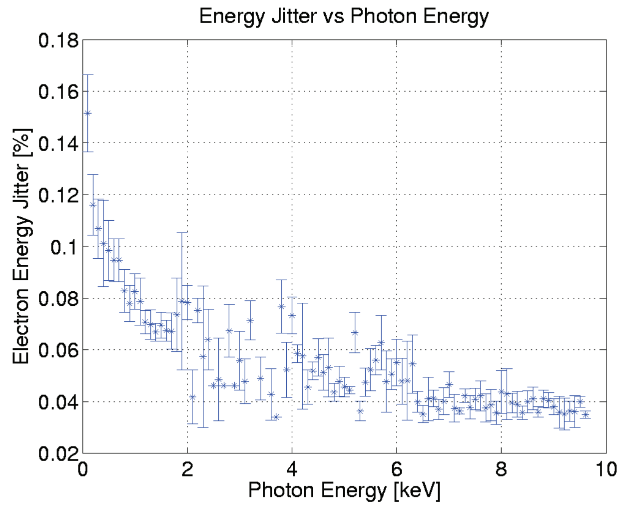

Figure 1: Four-month history of energy jitter versus photon energy. Jitter decreases from 0.15% to 0.05% for soft x-rays and is around 0.04 % for hard x-rays. A special L3 phase setup of -15° reduces it further by about 20%. Energies between 2 and 5 keV are seldomly used, so the error bars are bigger.

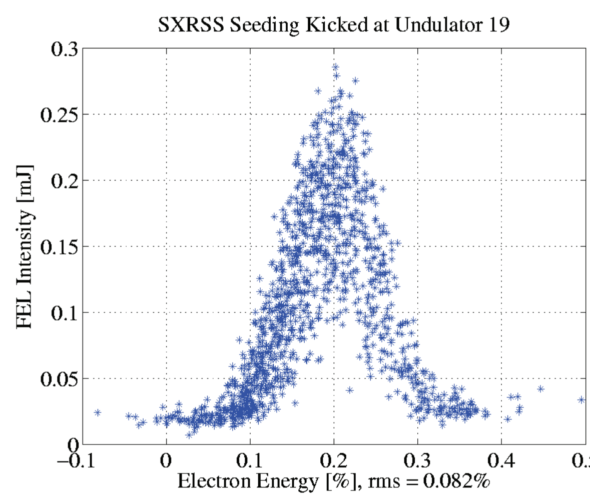

Figure 2: Soft seeded intensity versus electron beam energy. Off energy beams do not seed, the jitter is with 0.082% more than 1.5 times the rms of the distribution (0.052% = ρ/2). The goal is half of the distribution rms.

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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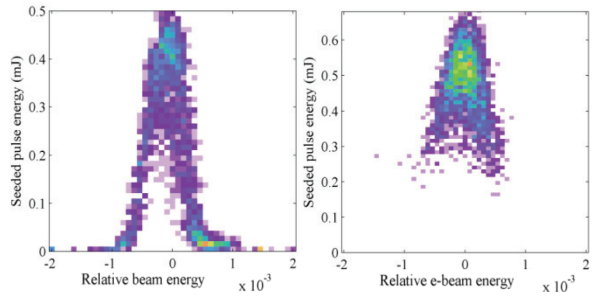

Figure 3: FEL intensity versus electron beam energy variations. With $\Delta E/E$ = 0.050% in May 2012 (left) the FEL intensity variation was about four times worse than at 0.025% in April 2014 (right).

ENERGY JITTER REDUCTION

New L1S SLEDed Setup

Many improvement projects were tried to reduce the phase and amplitude jitter of L1S, the most sensitive RF station. A project in which a secondary power supply should fine regulate the high voltage to 20 ppm, did not help very much, so that with the present thyratron jitter the modulator voltage jitter was too high (140 ppm). This required lowering the high voltage from 350 to 300 kV, making a SLEDed (SLAC Energy Doubler) operation necessary. Two changes were introduced, one for going between SLED and unSLED easily and the other to reduce phase jitter. With these improvements the energy jitter reduced to below 0.025% for hard x-rays and L1S was no longer the top jitter source, Fig. 4.

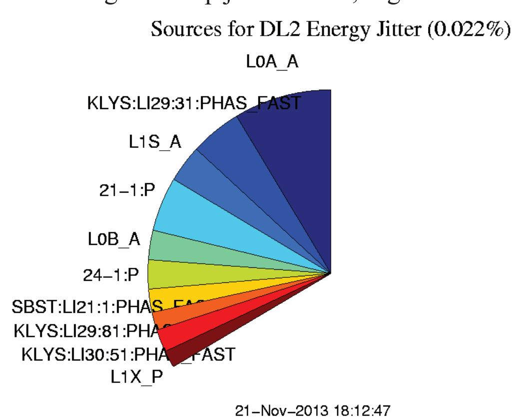

Figure 4: Jitter pie of sources of energy jitter. The RF stations in front of BC1: L0A, L0B, L1S, and L1X are significant. Also stations in the energy feedback Li29/Li30 where the phase is too close to 90° are often a part of the bigger sources.

To go easily between SLEDed and unSLEDed we chose a special waveform (Fig. 5), where after the 180° switch the amplitude is slowly ramped up. This produces an RF pulse form similar to unSLEDed, so there is no additional transverse beam tuning necessary.

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° to 0.035°. Explanations might be the timing of the unsteady reflection at the RF loads, or the softer slope reducing the load multi-pacting variations.

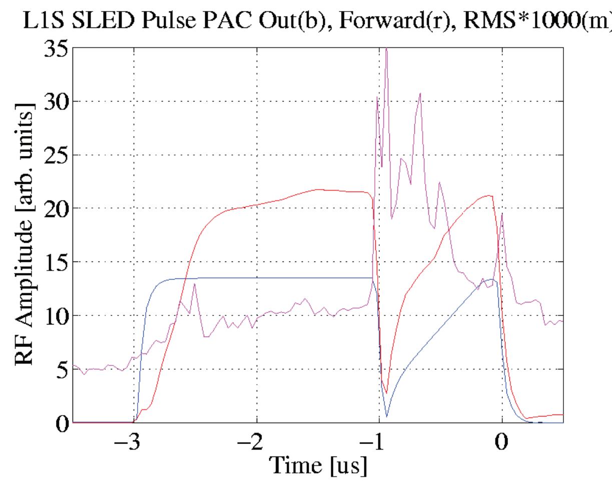

Figure 5: Special L1S SLED waveforms. The amplitude after the 180° switch at -1 µs is slowly ramped up with the phase and amplitude control (PAC, blue) giving a flatter integrated waveform after the SLED cavity. The forward pulse after the klystron (red) is additionally cut early by timing the modulator late. This causes the unsteady reflection in the RF load after the accelerator structure to fall near -1µs 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).

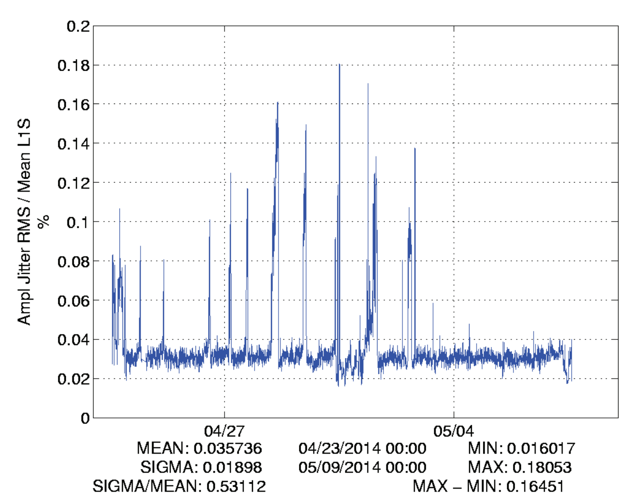

Figure 6: Short periods of increased amplitude (only) jitter of L1S caused the final beam energy jitter to increase 2-3 fold.

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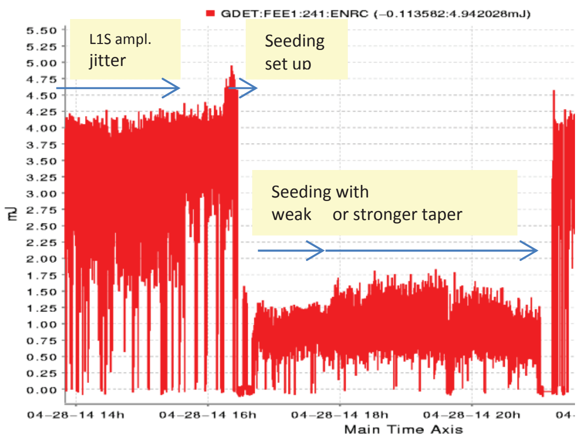

Figure 7: FEL photon intensity in mJ. The initial strong variations from 1.5 to 4 mJ were caused by L1S amplitude jitter. The problem disappeared an hour before the seeded set up of 20 min and following run with different taper setting and peak seed powers up to 1.5 mJ.

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%.

TRANSVERSE JITTER SOURCES

After having problems with air flow over a laser table at the injector causing large transverse jitter (33 instead of 5 µm) our awareness to transverse jitter was raised. We also identified the source of a 42 Hz line (half of the 5 µm jitter) at the laser table in the vault near the gun.

Transverse jitter causes besides the FEL pointing stability, also FEL intensity variations. When it is linearly correlated with beam positions in the undulator we found that by small launch changes causing 20 µm orbit excursions, the FEL performance gets optimized.

At the optimum, no linear correlations are present and finding the biggest sources is not easily possible. We have started to fit up to second order to find the biggest sources, see Fig. 8. The good RF BPMs (Beam Position Monitors) in the undulator show the biggest correlation in *x* and *y*, while often residual dispersion is indicated by correlation with energy BPMs.

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

[1] F.-J. Decker et al., "Increased Stability Requirements for Seeded Beams at LCLS", FEL2013, New York, USA, WEPSO10, p. 518 (2013); http://jacow.org

[2] D. Cocco et al., "The Optical Design of the Soft X-ray Self Seeding at LCLS", Proc. SPIE 8849, 88490A, September 30, 2013.

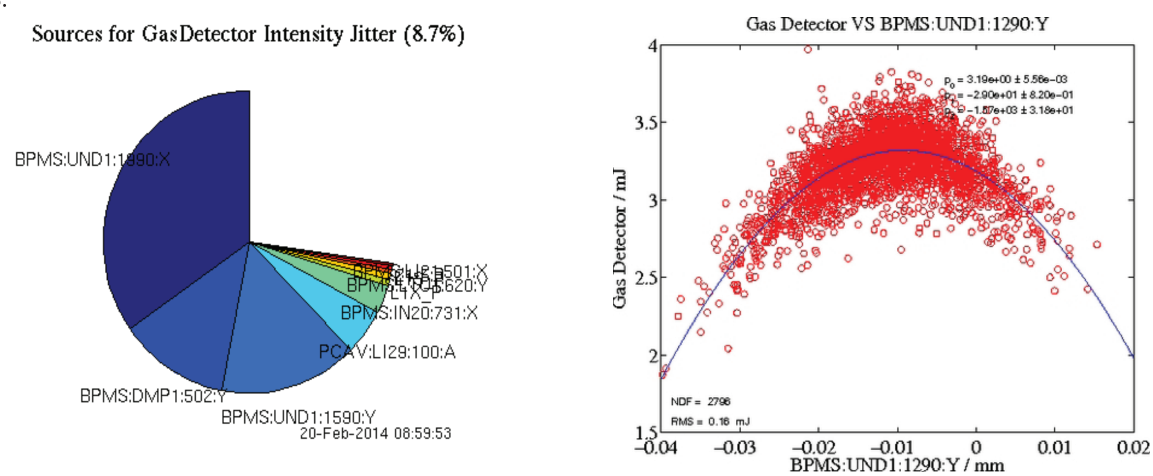

Figure 8: The FEL intensity shows only second order jitter when optimized. Linear correlations cannot be used to identify jitter sources. Here the second order fit was used to quantify contributions.

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