

IDENTIFYING LONGITUDINAL JITTER SOURCES IN THE LCLS LINAC*

F.-J. Decker, R. Akre, A. Brachmann, J. Craft, Y. Ding, D. Dowell, P.J. Emma, J. Frisch, Z. Huang, R. Iverson, A.K. Krasnykh, H. Loos, H.-D. Nuhn, D. Ratner, T. Smith, J.L. Turner, J. Welch, W. White, J. Wu, SLAC, Menlo Park, CA 94025, U.S.A.

Abstract

The Linac Coherent Light Source (LCLS) at SLAC is an x-ray Free Electron Laser (FEL) with wavelengths of 0.15 nm to 1.5 nm. The electron beam stability is important for good lasing. While the transverse jitter of the beam is about 10-20% of the rms beam sizes, the jitter in the longitudinal phase space is a multiple of the energy spread and bunch length. At the lower energy of 4.3 GeV (corresponding to the longest wavelength of 1.5 nm) the relative energy jitter can be 0.125%, while the rms energy spread is with 0.025% five times smaller. An even bigger ratio exists for the arrival time jitter of 50 fs and the bunch duration of about 5 fs (rms) in the low charge (20 pC) operating mode. Although the impact to the experiments is reduced by providing pulse-by-pulse data of the measured energy and arrival time, it would be nice to understand and mitigate the root causes of this jitter. The thyatron of the high power supply of the RF klystrons is one of the main contributors. Another suspect is the multi-pacting in the RF loads. Phase measurements down to 0.01 degree (equals 10 fs) along the RF pulse were achieved, giving hints to the impact of the different sources.

INTRODUCTION

The electron beam for an FEL has besides small transverse emittances, an especially small longitudinal emittance. After compressing the beam by more than a factor of 100 the beam energy spread is still of the order of $1E-4$. With this the beam is much smaller than the stability of the RF system. To illustrate this Fig. 1 shows the difference between 20% jitter (transverse) and 500% longitudinal, where an overlap with another beam would be random.

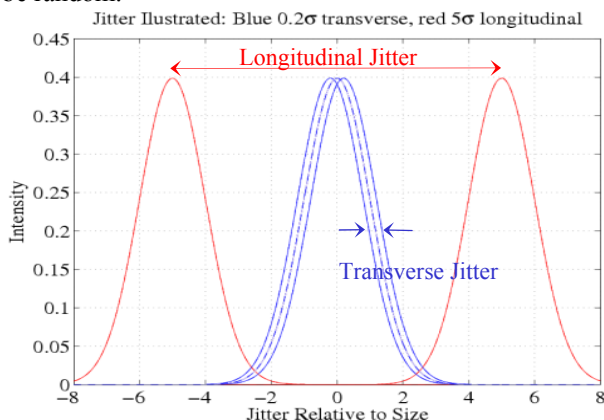


Figure 1: Comparing jitter 20% and 500% of sigma.

An even better example is shown in Fig. 2 where the measured energy distribution is shown before and after jitter correction, where the beam centroid of the distribution is measured by a Beam Position Monitor (BPM) in a dispersive region and corrected shot by shot. It illustrates that the measurement technique is much better than what is used to create the beam.

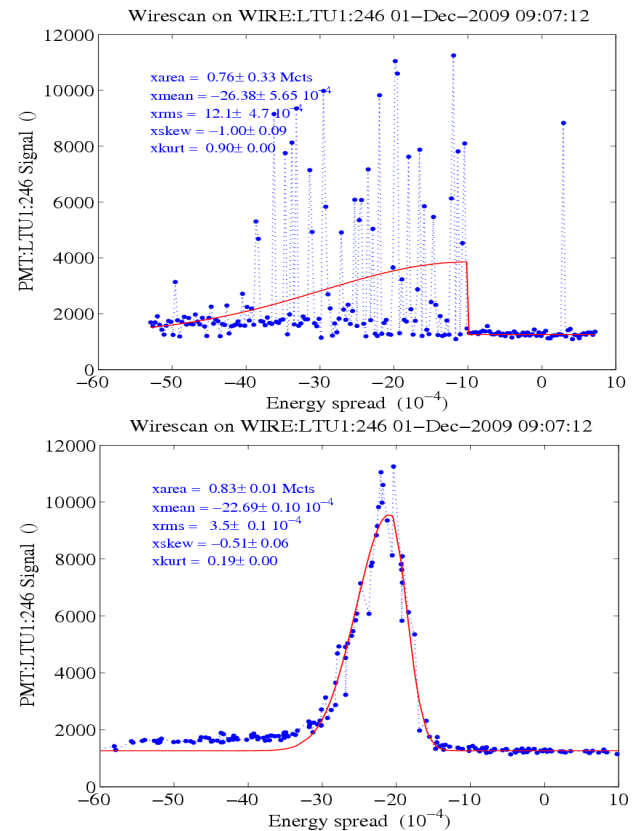


Figure 2: Energy spread distribution before (top) and after (bottom) jitter correction. This measurement was with a peak current of 1.25 kA and an energy of 5.811 GeV.

RF SYSTEM OF THE LCLS

Description

The RF system for the LCLS uses the nearly 50 year old SLAC Linac and delivers power to the four LCLS linac sections: L0, L1, L2, and L3. Besides accelerating, the RF introduces a correlated energy spread (or chirp) in L1 and L2 in front of the bunch compressors BC1 and BC2. Any phase jitter causes energy jitter and due to the different delays through the bunch compressor, arrival time jitter in the next section. Since one klystron, L1S, delivers 135 MeV out of 250 MeV before BC1 and most of the chirp, it is by far the biggest source of jitter.

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RF Jitter Tolerances

The RF jitter tolerances for amplitude and phase of 0.1% and 0.1° [1] seemed to be fulfilled even for LIS most of the time. Initial attempts, making the RF pulse shorter by filling the SLED cavity only a short time, and raising the klystron voltage, helped a little for stability. But where was the high level of bunch length and energy jitter after BC2 coming from? Was it the effect of coherent synchrotron radiation (CSR) in BC2 and therefore the principle limit of the setup?

The answer was found in the following way: The measured LIS phase jitter was inconsistent with the measured bunch length jitter, but it was still highly correlated, so at least part of the jitter was coming from it [2]. By investigating the RF setup it was found that the phase and amplitude measurement was averaged over 400 ns while the fill-time of the accelerating structure is more like 825 ns. Increasing the time over which the measurement was taking place increased the jitter, which was bad for the Low Level RF (LLRF) feedback system actually increasing the jitter by the feedback. Historically it was thought that the “measured” jitter was “best” for the first 400 ns.

Taking the later 400 ns of the 800 ns (with LLRF feedback off) the jitter actually increased even more beyond the tolerances and it showed a very high correlation with the BC2 bunch length signal (peak current), see Fig. 3.

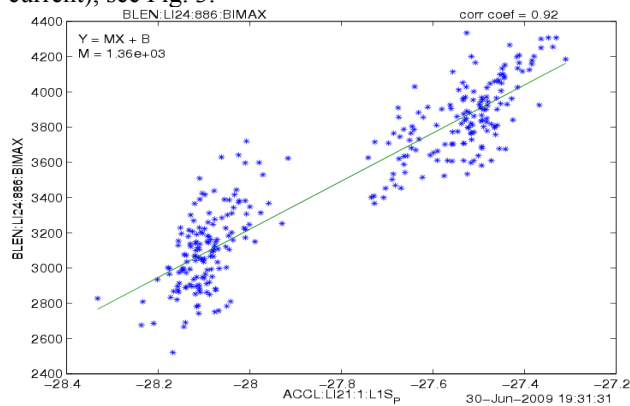


Figure 3: BC2 bunch length (peak current in A) versus LIS accelerator phase (in deg). Besides the high correlation of the two signals there is a two-state visible, where one state is more stable than the other.

RF JITTER OF LIS

Two State Jitter

A two state jitter was directly visible and a chase began to pinpoint the root cause of it. It was also noticed that one state had much more stability than the other, and the rms phase jitter was with about 0.05° half the tolerance.

Two candidates are always on the list, if there is trouble with RF: The high voltage supply for the klystron, or the RF system itself. Since there was multi-pacting observed in the RF loads at the exit of the accelerating structure, magnets were installed on the loads to suppress it.

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Additionally, we studied the raw RF waveforms to confirm the two-state, trying to find the root cause. The mixed down signal of the RF of LIS going into the accelerating structure was used. Zooming in of 30 overlaid pulses the characteristics of the two-state was also observed, including different amounts of jitter. The signal was taken off the RF before it goes into the accelerator, so the multi-pacting later in the pulse seemed not to be the root cause.

High Voltage Pulse

The 350 kV high voltage pulse (or part of it) is also available as waveform over about 5 μs (or 512 points max). By subtracting the average of about 20,000 counts from the 30 signals many structures are revealed (Fig. 4). An immediate improvement could be made by moving the high voltage pulse 1.5 μs later (actual move).

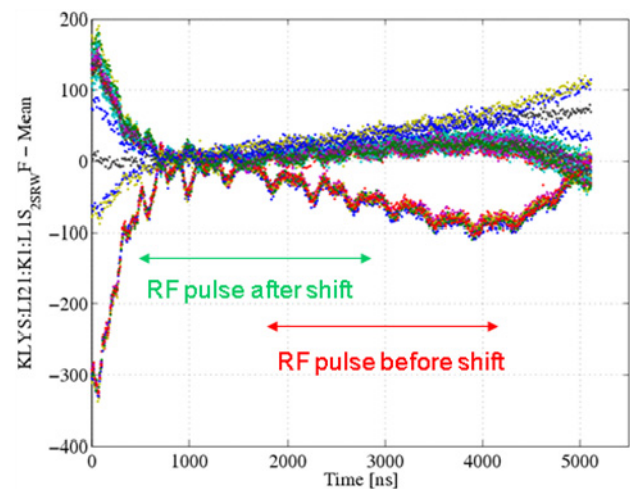


Figure 4: High voltage pulse differences to mean versus time. There is a two-state visible especially near 4000 ns of about 0.7% (140/20,000), there is some structure with about fourteen ripples (PFN has 16 capacitors), the RF stability could be improved by shifting the RF pulse (with SLED) 1.5 μs earlier with respect to the high voltage.



Figure 5: High voltage pulses as scope traces. After the main pulse of 5 us the thyatron can switch off in many different ways in the following 100 μs.

Then the high voltage generation with modulator and thyatron were studied. It was directly apparent that something was wrong, even the sound of the modulator had a two-state. It was known that the thyatron could have a “back swing jitter” when it switches off many tens of microseconds after the main pulse, see signals in Fig. 5. There the negative 5 μ s signals are visible with different 100 μ s long time traces for switching off. The thyatron was finally replaced by a new, “good” one, after which the rms phase jitter measured over 800 ns improved to 0.055 ps.

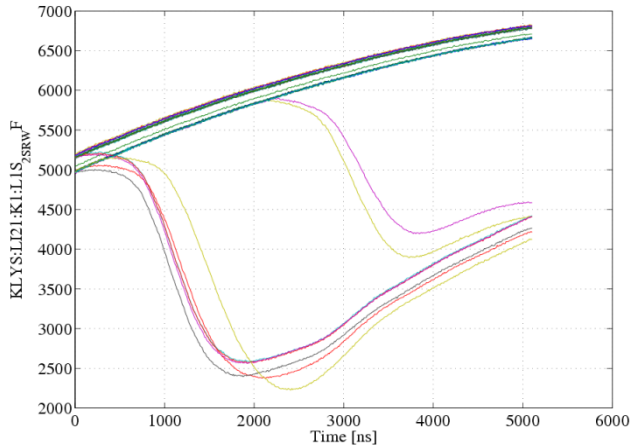


Figure 6: High voltage pulses 12 μ s later, swinging over to the positive side. It seems to create here a wide separation of about 2500 counts or 12 % of the main pulse, which might be the base for the next two-state.

It is still not understood how the switching off of the thyatron can influence the next pulse, whether the charging is different, or the thyatron has a memory effect. Fig. 6, which might support the idea of the next pulse effect, shows the high voltage pulse 12 μ s later, swinging to the positive side and then continuing either more stable to higher positive values, or breaking down at different times, e.g. 1000 and 3000 ns and forming a wider band and therefore a more jittery second state.

SUMMARY AND OUTLOOK

With all the efforts mentioned above to stabilize the klystron LIS, its phase jitter was reduced from effectively 0.20° (measured less at that time) to nearly 0.05°. But judging from Fig. 1 and 2, which were taken after the improvements, another factor of 4 seems necessary. One way to study the phase stability is to take part of the RF waveform and calculate the phase and compare this with different times of another waveform phase (see Fig. 7). RMS jitter numbers down to 0.01° or 10 fs were achieved, looking at the phase difference between the input and output of the same 10 foot accelerator structure. Worse numbers of 0.03° and 0.04° for the further away structures indicate something is happening over the length, or the multi-pacting in these lower power structures is seen. There is also the problem visible that the phases separated by 1000 ns are very little correlated and the rms jitter grows to about 0.08°.

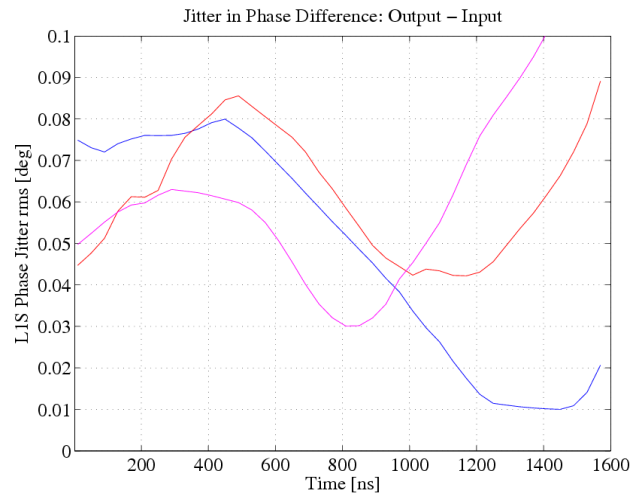


Figure 7: Best phase measurements. By taking the difference between input and output of the accelerator section phase rms numbers down to 0.01° can be measured for the different sections B (blue), C, and D.

On a good note the transverse effects of the longitudinal jitter due to dispersion can now be quickly reduced, by taking advantage of the jitter. Fig. 8 shows the slopes of a few undulator BPMs versus an energy BPM at 125 mm dispersion. These measured jitter slopes are plotted versus a corrector of a three corrector bump which generates some dispersion. The best setup is quickly found looking for the smallest spread.

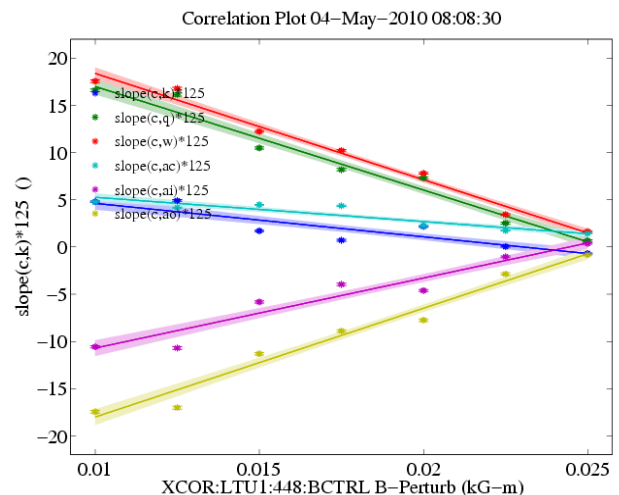


Figure 8: Dispersions in undulator versus a corrector of a 3-corrector bump. The initial settings (0.0175 kG-m) created about ± 10 mm dispersion, while with the final at 0.025 kG-m the dispersion is reduced below ± 2 mm.

REFERENCES

- [1] P. Emma, J. Wu, “Trajectory Stability Modeling and Tolerances in the LCLS”, EPAC06 Edinburgh, p.151.
- [2] F.-J. Decker, et al., “Identifying Jitter Sources in the LCLS Linac”, Linac08, Victoria, BC, Canada, p. 506.