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FEL BEAM STABILITY IN THE LCLS*

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Abstract

During commissioning and operation of the Linac Coherent Light Source (LCLS) x-ray Free Electron Laser (FEL) at the SLAC National Accelerator Laboratory electron and x-ray beam size, shape, centroid motion have been studied. The studies, sources, and remediation are summarized in this paper.

INTRODUCTION

Over the years different approaches to beam stability and jitter have been investigated, starting from tolerance calculation [1] before LCLS operations, to studying and identifying jitter sources and improving stability of the electron beam [2-5] during LCLS operations. Here we will concentrate, beside some newly discovered sources, on the effect of the jitter on the FEL photon beam performance, including transverse parameters, like centroid, size and asymmetry, and its overall intensity.

GENERAL APPROACH TO JITTER

When data is taken for a broad array of scientific endeavours, the general approach by experimenters is to collect as much data as possible on a pulse-by-pulse basis. Much of this is used to either make cuts in data sets or re-normalize to known effects of changing parameters, but losing data, or making less than perfect corrections are not desirable. So, though we work to achieve calculated tolerances and eliminate newly discovered sources, the goals are ever changing.

So when the stability performance of the beam is not good enough (and it by definition never is) we try to find the biggest offender by measuring many (~600) beam parameters synchronously at a sample rate of 120 Hz. FFTs and correlations can help to pinpoint the sources.

Fast Fourier Transform

By using a Fast Fourier Transform (FFT) we can identify special lines in the spectrum (Fig. 1) and then plotting the inverse FFT of that line versus z along the accelerator we can find its origin (Fig. 2). The 42 Hz from Fig. 1 was tracked down to the power supply of the very first x-corrector inside the gun-solenoid, which doesn't really have an iron core (for the corrector), so that fast (1.6 kHz) components can influence the beam. A similar power supply for a fast feedback corrector (air core) had a problem with 800 Hz. The low frequency component below 1 Hz is coming normally from feedbacks and the 11 Hz line hasn't been identified yet (somewhere near Bunch Compressor 1).

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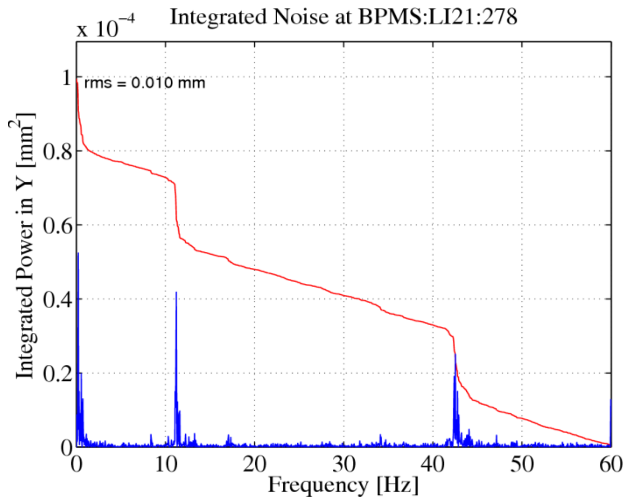

Figure 1: Power (blue) spectrum and integrated power (red) for a BPM in *y* in the LCLS Linac indicating 55% of the jitter power is coming from lines at 1, 11 and 42 Hz.

Our accelerator water pumps create lines near 59 Hz, mainly in *x*. When taking many data points, like 2800, it is possible to distinguish between different pumps with spectral lines at 59.03 and 58.9 Hz. The first line starts in Sector 28 in the Linac (Fig. 2) and the other (smaller) line in Sector 20 or 21. There are three approaches to this known 59 Hz problem: Identify the worse pump and replace it, mechanically stabilize vibrating quadrupoles with struts to the wall (Fig. 3, further installations are ongoing), and finally reduce the remaining part with a fast feedback as used during the SLC era [6].

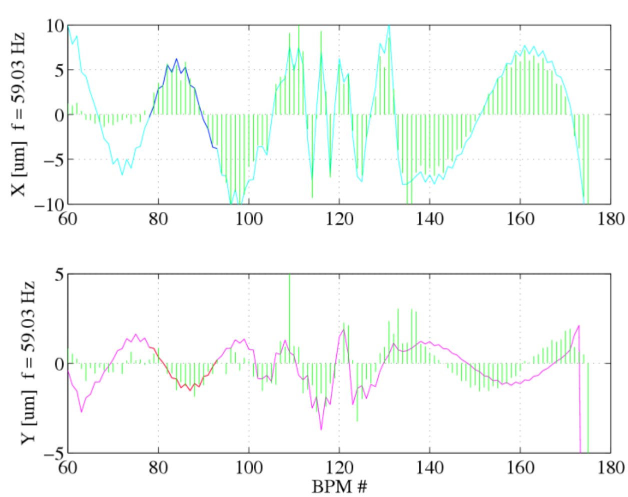

Figure 2: The 59 Hz component (mainly in *x*) generated by Linac accelerator pumps can be located here to the 5th quadrupole in Sector 28 in *x* and the 8th in *y*.

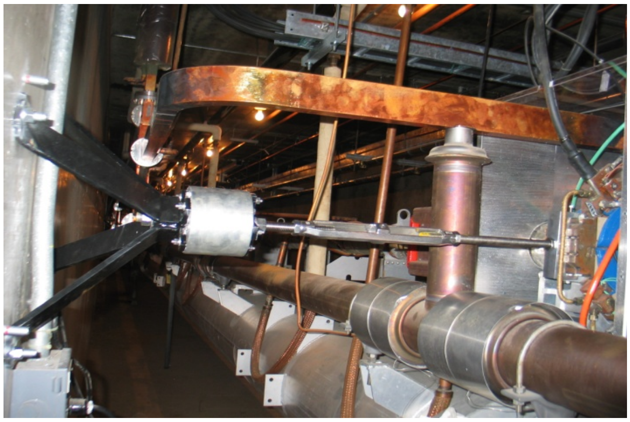

Figure 3: Wall strut for suppressing horizontal motion of a quadrupole.

Correlation Plots

For random noise jitter, without a distinct frequency line, we can find sources by plotting x and y of all the beam position monitors (BPMs) versus one jittery beam parameter and looking at the correlation coefficient or the slope versus z. This pinpoints the source location of the jitter in most cases very well, like the BXG magnet of the gun spectrometer, which was supposed to be off. Other times finding the actual source can be very tricky as it was the case of a strange two-state random x-jitter (Fig. 4). The source location was between the two cavities from L0 (Fig. 5): L0A and L0B, it was actually pointing to the YAG03 screen, which was partly decommissioned, and there are also four correctors and two quadrupoles around that area. A correlation with the beam-synchronous RF amplitude and phase of L0A and L0B didn't indicate any correlation. So the chase for checking any candidate for the transverse jitter was on, and we checked some power supplies two or even three times.

An unrelated question (by P. Emma), whether we have seen any problems with having only one output coupler for L0A (it has two symmetric inputs) gave the right hint. We negated that question, but directly went to work to check out whether the reflected RF waveform from the load was the culprit. The RF is not all damped in the load, and at random times multi-pacting occurs (creating a random two-state) which reflects the RF. The RF pulse was relative short (900 ns) compared to the 825 ns fill time, so the onset happened right at the time when the beam passes by the output coupler cell.

No correlation was found with the forward propagating phase and amplitude averaged over 800 ns, but some correlation (58%) was found with the backwards propagating reflected wave. By increasing the RF pulse width and adjusting the timing the x jitter was reduced from 4.5% to 3% of the beam size σ.

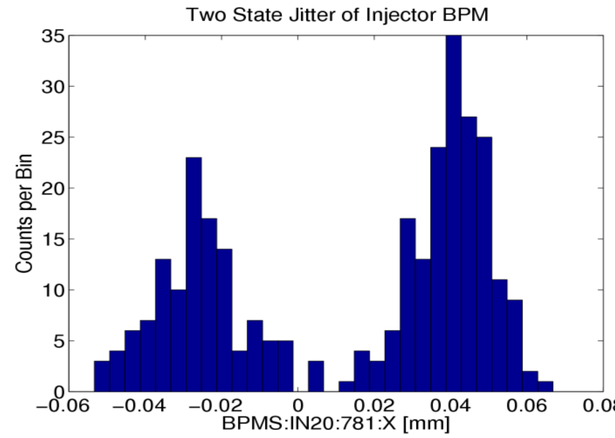

Figure 4: Two-state random jitter was finally tracked down as transverse RF kicks at the L0A load.

FEL PHOTON BEAM STABILITY

The photon beam stability of the FEL depends on the electron beam stability in certain ways. So the photon energy jitter is at least twice the electron energy jitter. The stochastic energy jitter of the SASE-FEL process adds on top of that.

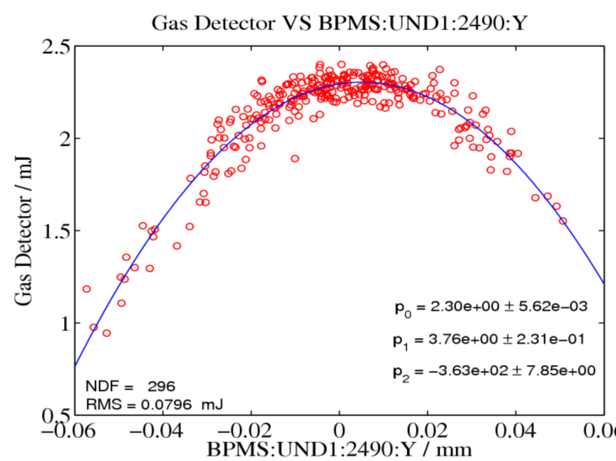

Figure 6: FEL intensity (mJ) versus Undulator y position, beam energy was 6.71 GeV. Any orbit variation outside of ±15 µm (or >5 µm rms) causes a reduced FEL intensity.

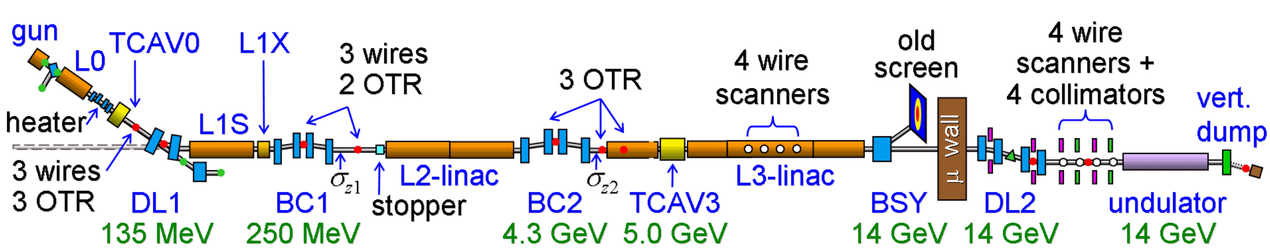

Figure 5: LCLS schematic layout of the Linac sections (L0, L1, L2, and L3) with the two bunch compressors (BC), followed by a dog leg (DL2) and some collimation before reaching the undulator and dump.

FEL Intensity

The FEL intensity varies pulse by pulse and is strongly correlated to the transverse position in the undulator in a quadratic way (Fig. 6). By reducing the transverse jitter the intensity can be reduced to less than 5 %.

FEL Transverse Position Jitter

The transverse jitter of the FEL photon beam is measured 110 m after the last used undulator on a YAG screen called Direct Imager, assuming to be another 25 m away from the FEL source point (L=135 m). So any jitter Δx in the undulator is about six times bigger there:

$$\Delta X = \frac{\Delta x}{\beta_x} \cdot L \cdot \frac{\beta_{\max}}{\beta_{\min}} \approx 6 \cdot \Delta x. \tag{1}$$

Figure 7 shows the rms electron jitter at different places in the undulator in x and y for two different days. And typical FEL photon beam parameters at the Direct Imager are summarized in Table 1.

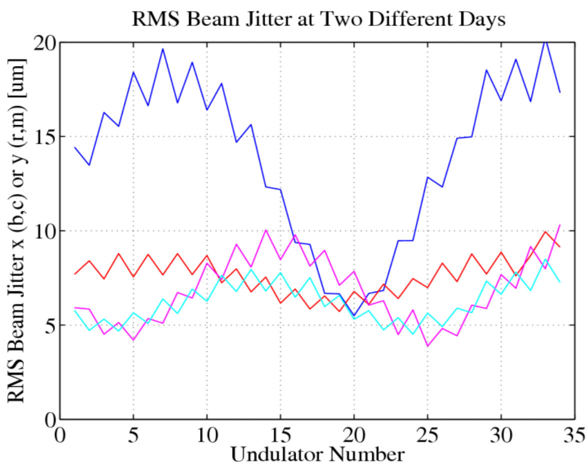

Figure 7: The RMS jitter is plotted versus undulator position for two different days (blue and cyan for x, red and magenta for y).

The FEL position on the screen has the highest correlation (>90%) with the electron position at the undulator number 24. This is very close to the expected FEL source point, although the highest correlation with the position should indicate the source to be closer to 90º away, where the angle would change.

Table 1: Typical FEL Photon Beam Sizes and Jitter [µm]

Energy	Intensity Jitter	Beam Size Range	Size Jitter	Position Jitter
14 GeV	12 ± 4 %	160 – 220	15	25 – 40
4.3 GeV	10 ± 4 %	750 – 900	30	30 – 45

FEL Size

The FEL beam size is proportional to one over the electron beam energy with some range. The relative fluctuation in the size goes down with lower energy, but the jitter of the position nearly stays the same (see Table 1).

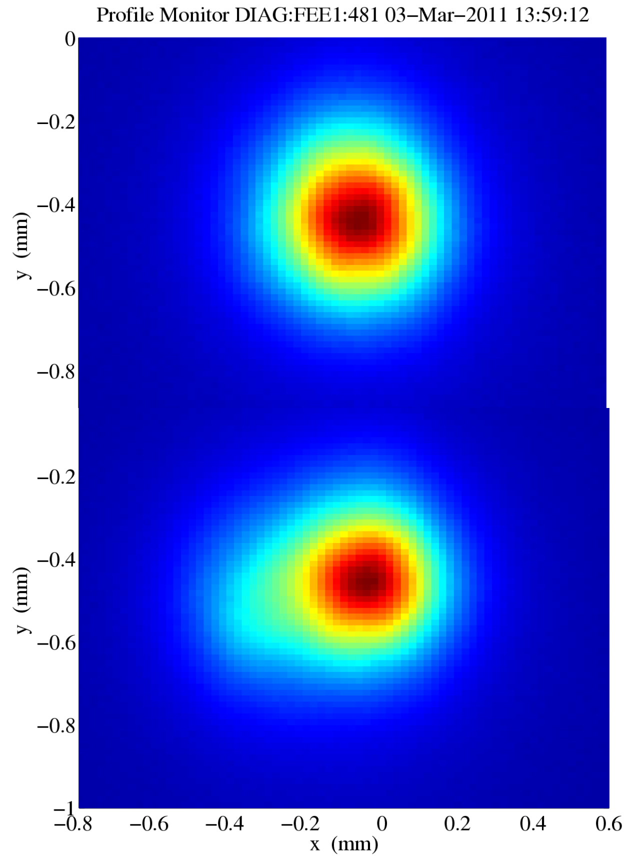

Figure 8: FEL spots on a YAG screen (Direct Imager), top with laser heater on bottom with it off at 150 pC charge.

FEL Distribution

Even the third moment or skew of the distribution changed pulse by pulse. Sometimes we have a strong asymmetry with a skew of 20±10% in x (Fig. 8).

SUMMARY

The overall FEL performance of the LCLS is setting precedents, but the jitter can always be improved. Some jitter sources were identified and fixed. Our focus has moved from electron jitter to photon jitter.

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