INCREASED STABILITY REQUIREMENTS FOR SEEDED BEAMS AT LCLS*

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Abstract

Running the Linac Coherent Light Source (LCLS) with self-seeded photon beams requires better electron beam stability, especially in energy, to reduce the otherwise huge intensity variations of around 100%. Code was written to identify and quantify the different jitter sources. Some improvements are being addressed, especially the stability of the modulator high voltage of a few critical RF stations. Special setups like running the beam off crest in the last part of the linac can also be used to reduce the energy jitter. Even a slight dependence on the transverse position was observed. The intensity jitter distribution of a seeded beam is still more contained with peaks up too twice the average intensity, compared to the jitter distribution of a SASE beam going through a monochromator, which can have damaging spikes up to 5 times the average intensity.

INTRODUCTION

There have been many efforts over the years from tolerance studies, identifying jitter source to improving stability of LCLS beam [1-7]. The overlap of the SASE photon energy with the narrow crystal line of the seeded beam energy requires that the energy jitter is smaller than the bandwidth of SASE beam or even smaller than some features of its distribution.

INTENSITY VARIATIONS

The main problem of seeded FEL beam stability is its intensity variation dependence on the electron energy. Figure 1 shows the intensity variation of a seeded beam going through a monochromator versus the electron energy measured in DogLeg 2 (DL2). There are two ways to improve the intensity stability, a) by reducing the energy jitter and b) by increasing the acceptance of the undulator or the width of the distribution in Fig. 1.

Effects of Reducing the Energy Jitter

Even without any energy jitter (center part of Fig. 1) there is some intensity fluctuation of about 20 % due to the random FEL process which cannot be much reduced. Ignoring this variation, assuming a perfect Gaussian distribution with a sigma of 0.042%, we can estimate the effect of the jitter on the average intensity and its RMS (Fig. 2). With the jitter equal to the width of the distribution (0.042%) the average intensity is 70% of the maximum and the variation 40%. Reducing the energy jitter to 0.02%, the average intensity would raise by 30% to the 90% of max level, while the intensity variation would be reduced by a factor of four to 10%, which is already smaller than the 20% from the FEL fluctuations, which you would get with not energy jitter. Therefore the goal is to achieve an electron beam energy jitter of 0.02% from the typical 0.04 to 0.06% at high energy. At low energy jitter numbers are typically between 0.1 to 0.15 %.

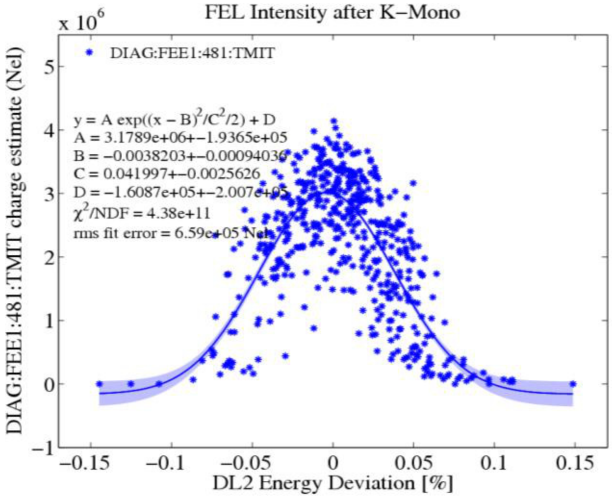

Figure 1: FEL intensity of a seeded beam after the K-monochromator versus DL2 energy. The sigma of the fitted Gaussian is 0.042% and corresponds to the acceptance of the undulator. It is about $\rho/2$ of the undulator and depends also on the beam energy spread.

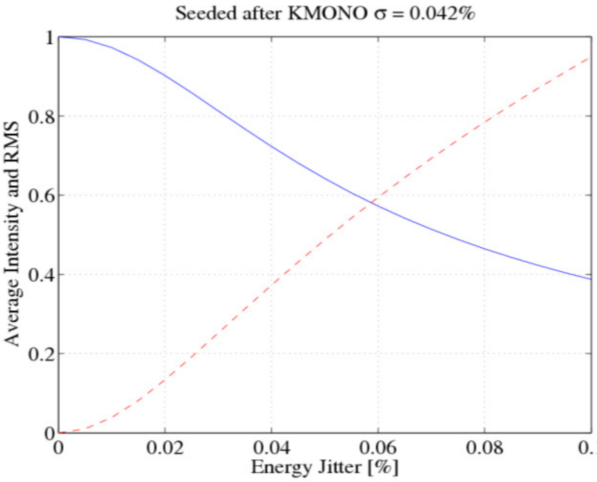

Figure 2: Assuming no SASE FEL fluctuations, the average seeded intensity (solid) is reduced due to jitter and its RMS (dashed) is increased: 0.042% energy jitter gives 70% of the peak and a variation 40%, while 0.020% energy jitter would give 90% of the max intensity with 10% rms variation.

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Increasing the Acceptance of the Undulator

The width of the distribution in Fig. 1 has varied between 0.025% and 0.050% at different times. But since most parameters get optimized for peak performance it might hurt the stability of the intensity, but mostly they go hand in hand. It has been observed that a slightly weaker undulator taper is good for intensity stability for SASE and a monochromator, but systematic studies are still lagging.

IDENTIFYING JITTER SOURCES

To identify and fix the main jitter sources has been done over the years. Now often many sources contribute with similar amounts of less about 5% to the final jitter sum (Fig. 3). To sum them up we plot the jitter powers, in this case the square of the correlation coefficients with the DL2 energy.

The final number of 0.030% was achieved during a seeded run after identifying one bad klystron in L2 (23-8), which was responsible for 16% of the measured energy jitter power. So the then-measured amount of 0.037% energy jitter should have been reduced by at least 8.3% (about half of 16% in power), but it was actually reduced from 0.037 to 0.030% (-19%) or 34% less in power.

The difference is actually the part of the jitter pie which is white, only part of the jitter is captured in its correlation with energy since there are measurement errors and mostly we leave the beam feedbacks on which tends to smear out some correlation and therefore reduce the correlation coefficient. At lower jitter (or low charge running) the measurement limitations start to play a roll, so we are confident that we will achieve roughly twice the measured value by eliminating jitter sources before L1.

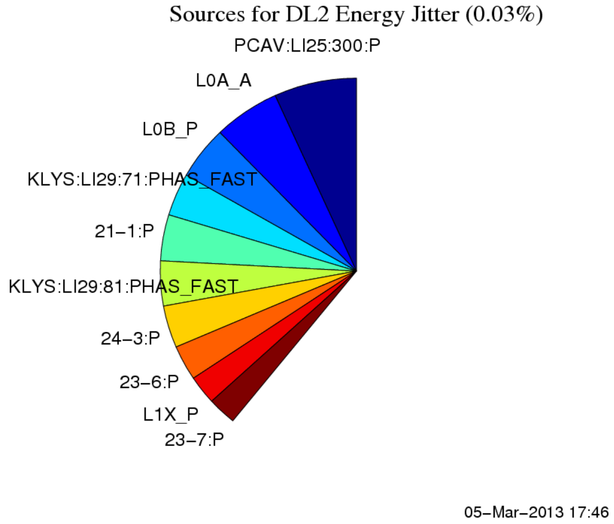

Figure 3: Energy jitter pie chart, showing that the klystrons stations (L0A, L0B, L1S, L1X) before BC1 (bunch compressor) are responsible for a good part of all the energy jitter.

JITTER TASK FORCE

Since a big part of seeded beam pulses is effectively lost due to low intensity, a task force was created, which should look into all different aspects of jitter. Theoretical tolerances, experimental observations and power supply upgrades were investigated. The most impacting results are described below.

Tolerance Studies

Tolerance studies have shown that we could reduce the jitter by a factor of two by adjusting certain longitudinal setups like phases, depending on the different amounts of jitter sources. So an L2 phase jitter can be compensated by an offset in the L3 phase. But a simple attempt to cancel phase variations around -36° for L2 with 5 GeV energy gain, by going to a +18° offset for L3 with 10 GeV gain didn't help, since there is a compression section (BC2) in between. This causes actually the sign to flip and that L2 and L3 should have similar phases if there wouldn't be any jitter from L3. An experimental study confirmed this effect (Fig. 4).

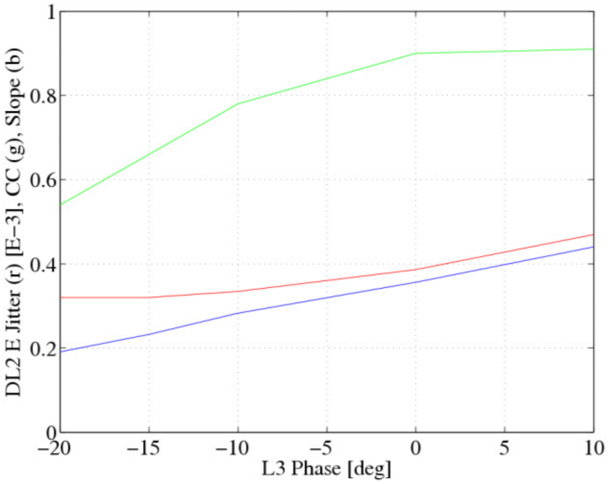

Figure 4: Energy jitter (red), the correlation coefficient of DL2 energy with BC2 energy (green), and its slope versus L3 phase offset (blue).

The energy jitter was reduced from 0.039 to 0. 032%, while the correlation coefficient reduced from 90 to 65% and the slope shows that it would intersect with zero near -45 deg, close to L2 phase, which the simulation predicted.

Another setup trick is to get some chirp already from L0 and additionally from L1X so the L1S part can be reduced. This requires more attention to the dispersion cancelation around DL1 and its second order compression requires more L1X amplitude. A quick test of L0B running 10° more negative showed that the correlation with L1S was reduced, but the overall jitter did not improve.

HV Power Supply Upgrade

The phase and amplitude jitter of a klystron is often highly correlated with the voltage of its modulator. By

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varying the tap on the primary side of the transformer the modulator voltage was changed from 350 to 360 kV and the respective phase and amplitude were recorded (Fig. 5). The phase dependence agreed within 5% of expectations, while amplitude slope was 40% steeper. A value of 5° per 1% voltage change corresponds to 0.05° per 100 ppm (typical) or even 0.03° per 60 ppm, which is the best achieved so far in normal operation.

If the L1S high voltage would be half of all the sources of jitter and we would like a final energy jitter of 0.02 % the following parameters are needed: $\Delta V/V$ = 40 PPM or 0.02° at L1S.

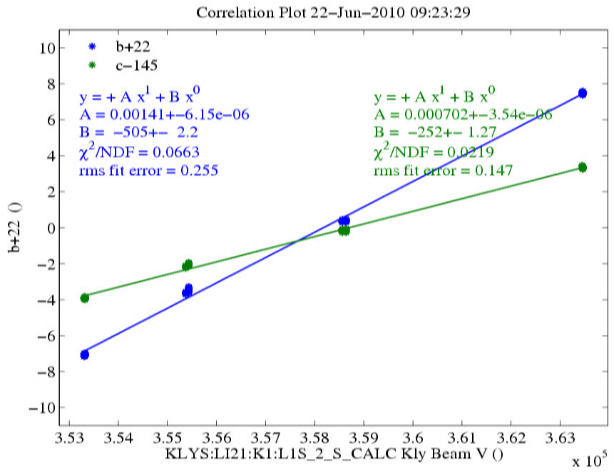

Figure 5: Phase (b) and amplitude (c) dependence on the voltage of its modulator. The phase change of 5° per 1% voltage change is consistent with theory, while the amplitude change of 2.5 MeV is somewhat larger.

These values are already close to normal high voltage and RF phase resolutions and hard to achieve. A value of 40 PPM noise floor was measured with no HV connected, and 0.02° is a value achieved with just a rectangular waveguide in between two phase measurement points.

So we decided to upgrade the L1S modulator with a second precision power supply (Fig. 6). This is done after already having a tail clipper, negative bias on thyratron grid, and de-Q'ing divider signal compensation for L1S [7] A test at another station confirmed 20 PPM, but the phase jitter at that station had other sources than the HV.

Other Jitter Sources

We are studying and trying to estimate other sources, like the high power RF in deep saturation and common power supplies, like for the klystron solenoids, where eight klystrons share on power supply. Progress is being made and procedures are being developed to quantify the acceptance of a klystron as a low jitter tube for LCLS.

PHOTON INTENSITY DISTRIBUTION

At the end the user of the photon beam has to struggle with the intensity variations after a monochromator. For SASE it is a gamma distribution with a shape parameter of one producing high intensity spikes, which might destroy a sample. The jitter produces a larger amount of low intensity reducing the average. For seeding the average is about 2.5 times higher than SASE going through a monochromator and no spikes are present. A flat taper, over-compression and a wider energy spread improve the distribution for SASE, it can be quite symmetric, but spikes remain (Fig. 7).

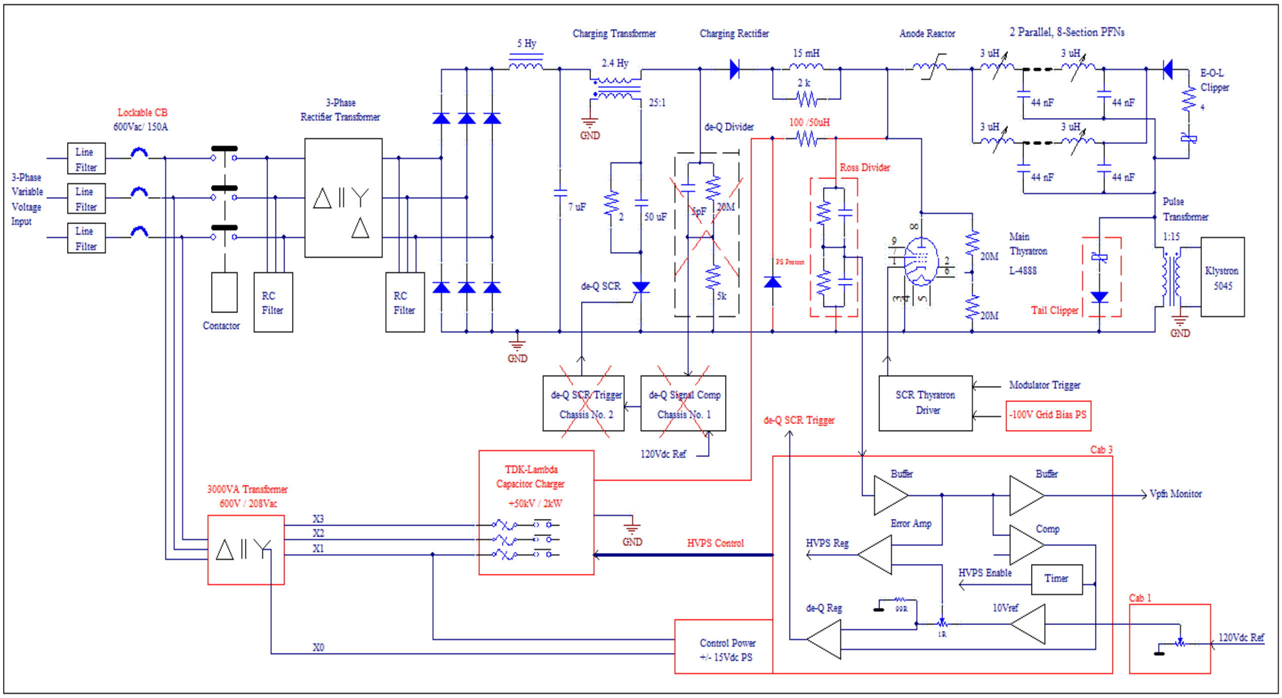

Figure 6: Modulator upgrade circuit, typical values: Modulator Output: 360 kV, 420 A, 150 MW peak, 90 kW average at 120 Hz. The second power supply (in red lines) regulates the last 0.5% of the voltage to about 20 ppm.

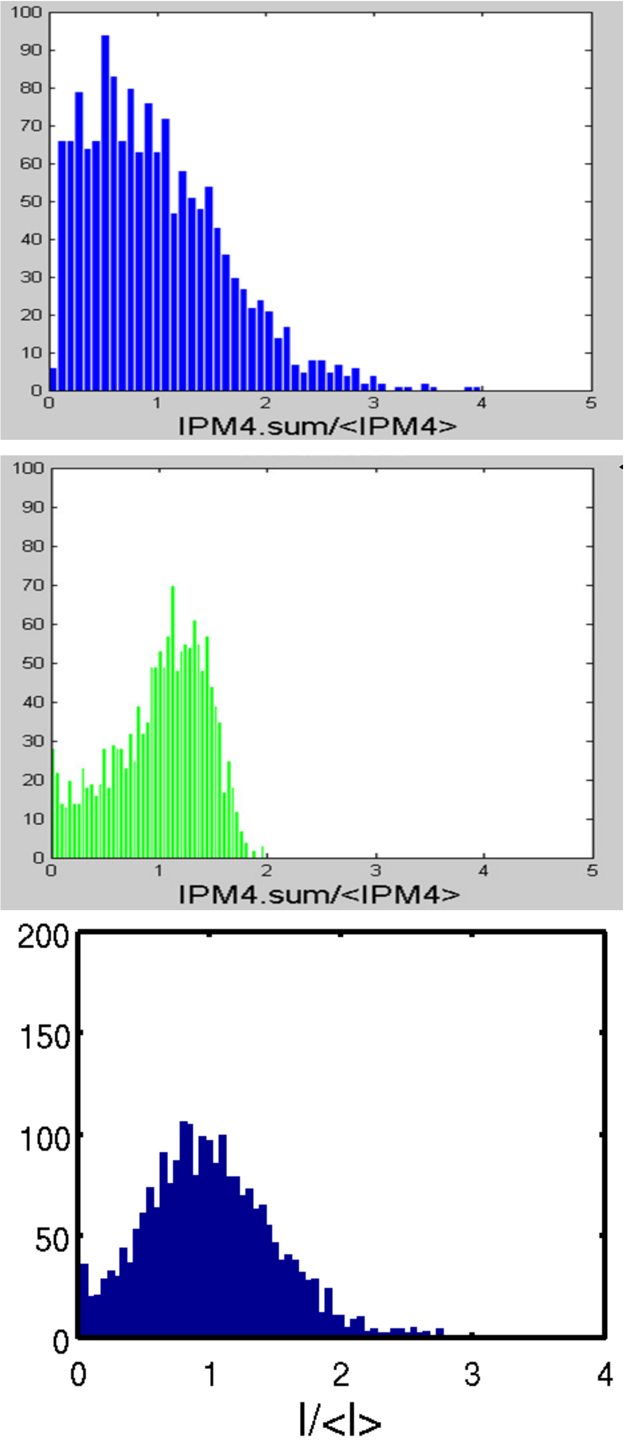

Figure 7: SASE (top) and seeded (middle) FEL intensity distribution going through a monochromator at XCS hutch [8]. The average of the seeded beam was 2.4 times higher than SASE. The SASE peaks around 0.6 with higher values up to 5, while the seeded distribution peaks around 3 and highs also up to 5. The recent symmetric SASE distribution (bottom, with some spikes up to 3) is close to the desired distribution [9].

SUMMARY

The stability of the LCLS electron energy has to improve by a factor of two from 0.04 to 0.02% to reduce the amount of non-seeded pulses and therefore the intensity fluctuations. Different techniques were presented which should help to achieve this goal. The best performing beam with 0.03% energy jitter demonstrated some progress, but further improvements are in the pipeline.

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