IMPROVING BEAM STABILITY IN THE LCLS LINAC*

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Abstract

The beam stability for the Linac Coherent Light Source (LCLS) at SLAC is important for good X-Ray operation. Although most of the jitter tolerances are met, there is always room for improvement. Besides the short term pulse-to-pulse jitter, we will also discuss oscillation sources of longer time cycles from seconds (feedbacks), to minutes (cooling systems), and up to the 24 hours caused by the day-night temperature variations.

INTRODUCTION

Recent papers discussed stability specifications [1,2] for the LCLS, short term pulse by pulse jitter sources [3] and their identification [4]. Here we will discuss first the long term variations of minutes to hours to days. Since feedbacks handle the overall measureable effect, like energy at the end of some of the linac sections, the first order effect is normally taken care of. If the energy error is not corrected where it occurs, the error propagates from the source to the feedback correction point and creates in this case a lattice error or mismatch of the betatron function. Another problem is when the drifts are too large so that the feedback hits a limit and doesn't regulate anymore. The third problem arrises when we make certain measurements, where the feedbacks have to be turned off and it is expected that the beam is stable over this "short" period for the measurement.

LONG TERM VARIATIONS

Long term drifts or day-night variations were already studied during the SLC-era. Some problems were understood and fixed with different tuning procedures [5]. Others were never tracked down but compensated with measuring up to six different variables [6], correlated with the daily temperature swings, and a feed-forward implemented to correct the unknown problem.

Since the RF distribution for the LCLS [2] was changed and we have now partly an old and partly a new system, it is more difficult to get the right parameter for the feed-forward. One of the most sensitive parameters is the L2 phase, since it determines the final energy and phase before the final bunch compression in BC2 (see Fig 1).

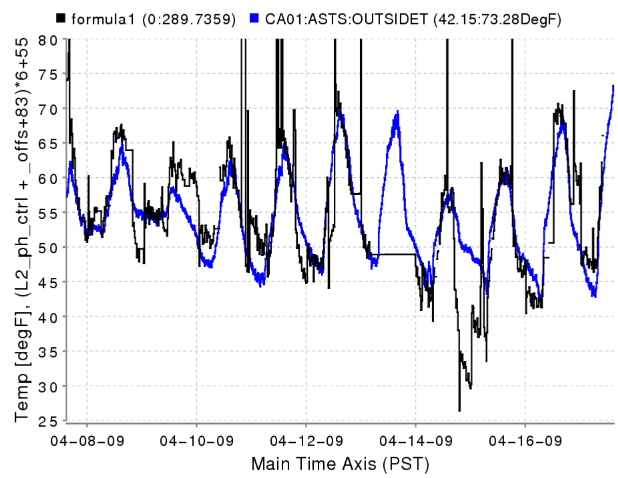

Figure 2: Outside temperature changes (blue) and overlaid the L2 phase (black, multiplied by 6).

The phase varies with the outside temperature by about 5° S-band for a 30°F temperature change (Fig. 2). Part is controlled by the bunch length feedback for BC2 (L2_ph_ctrl), while another part is hidden in the offset of the L2 phase, which changes only a few times a day when a manual phase scan is applied and the phase corrected. By adding the two we see the whole daily variation which is about 5°. The normal operating point for the bunch length feedback is −36° for the L2 phase, and since this is close to the maximum compression (around 40°) the feedback limit is set to −38.5°. This is only 2.5° away or half of the daily swing.

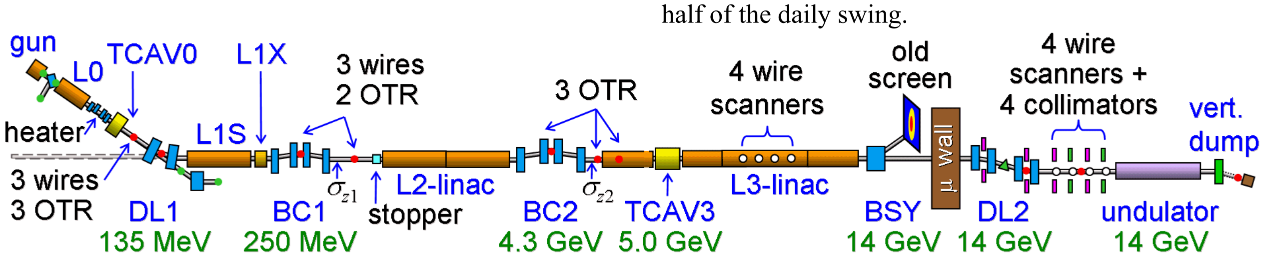

Figure 1: LCLS schematic layout of the Linac sections (L0, L1, L2, and L3) with the two bunch compressors (BC) followed by a dog leg (DL2) and some collimation before reaching the undulator and dump.

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This creates not a problem during the work week when the manual phasing is done near the beginning of each shift (8 am, 4 pm, midnight) since a little after 8 am and after 4 pm the temperature is the daily average. A problem arises during the weekend, when there are 12 hr shifts, changing at noon and midnight. The noon phasing near the heat of the day adjusts the phase offset in such a way that before midnight (around 10:00 pm) the feedback reaches its minimum (–38.5°) and stays there while the bunch length gets slowly longer. At the end of April 12th (see Fig. 2 the flat part) it happened requiring an early phasing.

Besides the L2 phase, which is planned to get a feed-forward soon using effectively the correlation of Fig. 2, there are some other phase drifts of maybe the gun and/or the laser phase. When phasing, we first adjust the laser phase to the gun phase being the reference, then L0A, L0B, L1S, L1X (compare Fig. 1). Often we see that the last four phases move together like 2°, 2°, 2°, 8° (X-band) indicating that the gun phase might be moving compared to the others. Looking at the beam phase cavity which is located after L0A (PCAV1 Fig. 3) we see that there is mostly a change when L0A phase (and laser phase) move, but there is also a daily variation of 0.75° visible.

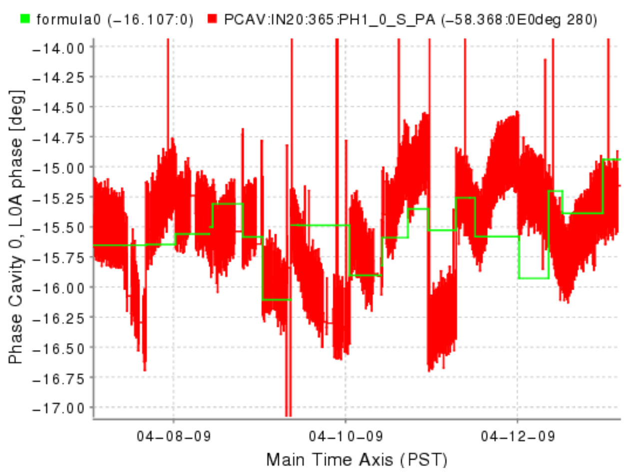

Figure 3: Beam phase (red) and L0A klystron phase (green) vs time. Beam phase is monitored continuously, while the klystron phase changes only after phasing.

MEDIUM TERM VARIATIONS

Medium term drifts of a few minutes or oscillations with that time scale are often generated by cooling systems. The cooling in most sensitive cases is variable (not on/off), but with high gains, typically set to minimize variations, and finite delays, oscillations, although small, are often seen. We have identified two different cooling loops from their period, a three minute period one, cooling the RF hut where the new RF distribution is located and a 5.7 minute one, in L2.

The 3-min oscillation is only very small just inside the tolerance of ±0.1°F, but it caused still quite some trouble when the outside temperature fell enough so that RF cable connection came loose and a phase jitter was observed every 1.5 min. After closing an outside door (at 2am in Fig. 4) the system slowly warmed up making only a phase jitter every 3 min till the beam got finally stable (Fig. 4). The next day tightening RF cable solved most of this problem.

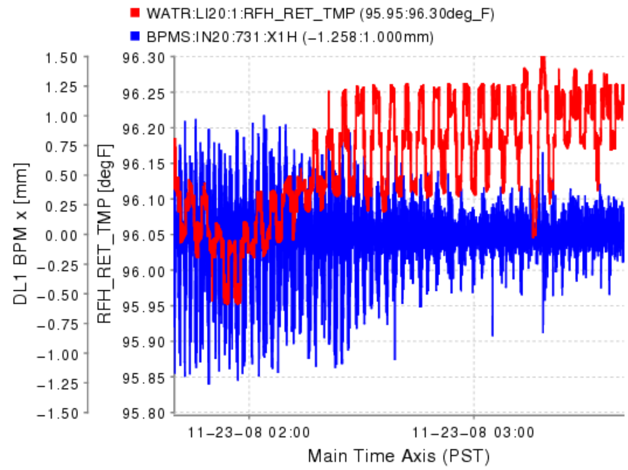

Figure 4: Small, but oscillating temperature variations of ±0.1°F caused energy jitter due to not tightened RF cables.

A 5.7 min oscillation is visible in the correction term of the BC2 energy and bunch length feedback. This is especially tricky since it is often switched off to run short measurements. When they last about 2.5 min the drift can biased the measurement, depending whether the scan was during the time when the L2 phase went up or down (Fig. 5). Here the root cause has to be found since the 0.4° phase variation causes 25% bunch length or peak current variation with the feedback turned off (Fig. 6).

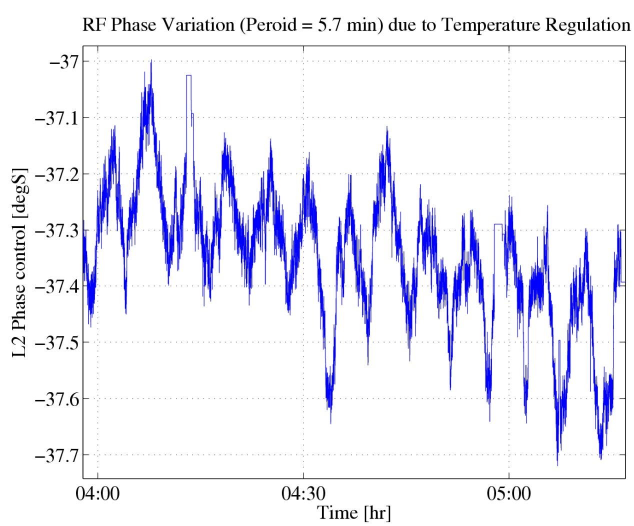

Figure 5: Medium term (5 min) variation of the L2 phase of 0.4°. The phase is controlled by a beam based feedback stabilizing the bunch length signal after BC2.

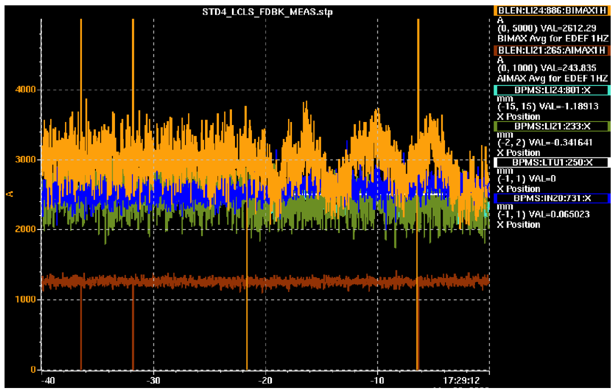

Figure 6: Medium term (5 min) oscillation of 25% of the BC2 peak current around 3000 A when the bunch length feedback is switched off.

SHORT TERM VARIATIONS

Many aspects of short term variation or jitter were already covered in earlier papers [3,4]. Here we will discuss some special aspects. The relative beam energy jitter is 3.3E-4 rms about three times bigger than the expected slice energy spread. When looking at the correlations with many other parameters, certain patterns show up, which give some insight. Figure 7 shows the jitter dispersion in x and y along the 175 beam position monitors (BPMs). This plot was generated from the slope of the correlation with the first DL2 dispersion BPM. There is some x-dispersion generated at BC2 and most of the y-dispersion comes from just before DL2 where a small vertical design dispersion doesn't seem to be fully compensated. Tab. 1 summarizes the off scale dispersions and compares them with the design.

DL2 dispersion is close to the design (by default) and the much bigger value of BC2 is also easily explained when assuming that the energy jitter comes from L2. The jitter would be strongly visible in BC2 at 4.3 GeV and

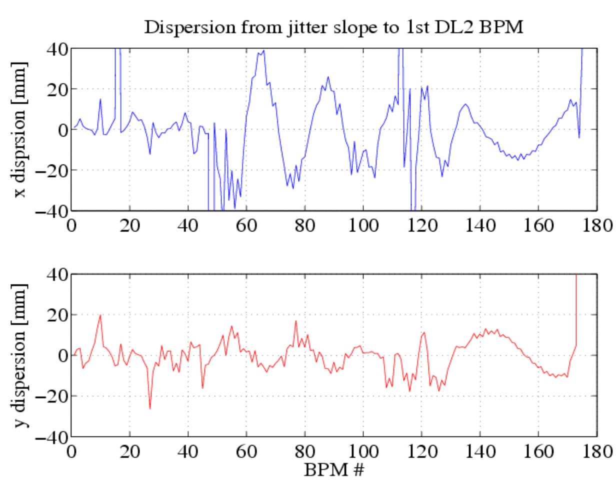

Figure 7: Dispersion derived from jitter measurement. Some x-dispersion is not contained in BC2 but leaks out and is about 10 mm in the undulator region.

Table 1: Design and Jitter Dispersion (3.3E-4 rms)

Location	BPM #	Design dispersion	Jitter dispersion
DL1	10	–263 mm	+15 mm
BC1	16	–231 mm	+215 mm
BC2	48	–362 mm	–943 mm
DL2	113/117	**125** / –125 mm	**125** /–122 mm
Dump	174/175	1235 / 700 mm	1695 / 1075 mm

reduced by the energy ratio 4.3/13.6 = 0.316 in DL2. So BC2 jitter dispersion should be 3.2 bigger than the design dispersion when all the jitter comes from L2, it is actually 2.6 times bigger indicating a large fraction from L2.

When the phase of L2 is varying not only is the energy in BC2 changed, but the bunch length is also significantly changed. A value of 8% rms in the peak current is observed and the correlation coefficient with the BC2 (or DL2) energy is -82%, but even -92% with the dump energy. This might explain the big discrepancy of the dump jitter dispersion of a factor of 1.45 more than design, since a shorter beam looses more energy in the undulator due to wakefields and FEL radiation.

Say the beam slips down the phase of L2 (more negative, -0.1°), it will have more chirp and less energy (–0.1%), and will be compressed more in the chicane to a higher peak current (+6%). The numbers in brackets were measured by quickly varying (dithering) the subbooster phase in Sectors 21, 22, or 23 and looking at the induced response. Normally operating the bunch length change is more like 11% for a –0.1% energy change indicating more than just a simple phase change as the root cause, one candidate is coherent radiation in BC2.

SUMMARY

Many small stability issues for LCLS have been identified and awaiting some correction. The long term daily oscillation can be corrected with a feed-forward, feedbacks take care of medium term drifts, and the short term jitter can even be used to measure beam parameter like dispersion.

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