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TIMING STABILITY AT LCLS*

F.-J. Decker‡, R.N. Coffee, W. Colocho, J.M. Glownia, K. Gumerlock, B. Hill, T.J. Maxwell, J. May, SLAC, Menlo Park CA 94025, U.S.A.

Abstract

The beam stability of the LCLS (Linac Coherent Light Source) has increased substantially over the years. Transversely it is a fraction of the beam size. The energy jitter was reduced from five times the energy spread to a fraction of it. Only the timing jitter is left. It got improved during the energy jitter reduction, but typically left alone. So we have five dimensions of the six-dimensional phase space covered with feedbacks and special 60-Hz jitter setups which eliminate the difference between every other pulse, but not for the general timing setup. We describe a scheme with the RF of the XTCAV, which could be used for other setups like lasers.

INTRODUCTION

The stability of the LCLS improved over many years. Transverse and energy jitter especially for seeding were the main concerns, and many papers were written each year till 2015 [1, 2, 3]. In this paper we concentrate on the timing jitter, since there seemed to be a disconnect between the typical 30 fs rms RF jitter versus the 300-400 fs timing jitter. Different aspects are discussed.

RF PHASE STABILITY

Many improvements to the high power RF stations were done over the years. The main source of jitter is mostly related to the switching of the thyratron. Anything over 35 fs (~0.035 deg S-band) is typically a sign of some degradation, like the Gun and L0B thyratrons needed replacement (see Table 1).

Table 1: RF Amplitude and Phase Jitter

LLRF	RMS/Mean Ampl.	RMS Phase
LASER	0.044 %	0.035 Deg_S
GUN	0.011 %	0.046 Deg_S
L0A	0.007 %	0.020 Deg_S
L0B	0.011 %	0.044 Deg_S
L1S	0.034 %	0.026 Deg_S
L1X	0.043 %	0.149 Deg_X

PHASE CAVITIES

Two phase cavities after the undulator are used for the beam arrival timing system [4], which generates and distributes an RF reference signal to the Near and Far Experimental Hutches (NEH and FEH). It gets also used for the XTCAV RF and XLEAP laser timing. Since there are two cavities with two fibre optics links to NEH and FEH there are four raw waveforms providing timing information (Fig. 1).

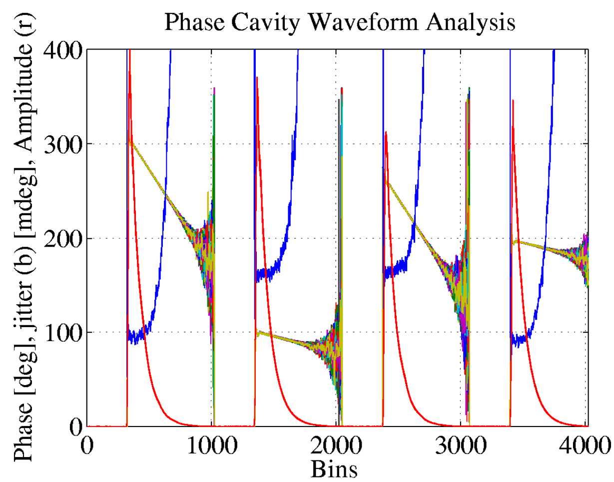

Figure 1: Phase cavity signals with four amplitudes and phases. The two cavities are differently tuned, see slope on 1st and 3rd signals versus 2nd and 4th. The phase jitter is lowest on signal 1 and 4 (FEH) while signal 2 and 3 (NEH) is dominated by every-other-pulse (or time slot) jitter.

Jitter Contributions and Sources

There are three main components: The RF link from the end of the Linac to the phase cavities, the two phase cavities themselves, and the optical links to NEH and FEH.

Time Slot Looking at the different possible combinations it is clear from Fig. 1 that the link to the NEH has the biggest jitter of about 170 fs rms (300 fs Time Slot (TS) separation). Initially the FEH link had an even bigger TS separation of 500 fs. It was found to be a small DC power supply for an RF fan-out, which delivers the RF reference to the FEH, XTCAV and XLEAP. Similar efforts to reduce the TS problem for the NEH didn't help.

Best Performance Looking only at one time slot the NEH with 54 fs rms performs actually better than the FEH (72 fs) still indicating a different problem with the optical link. The phase cavities themselves are with 12 fs very good (Table 2).

Table 2: Best Timing Performances (rms in fs)

	1	2	3	4
1		55	53	12
2			12	72
3				72
TS	3	300	310	9
old	410	350	340	500

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† Decker@SLAC.Stanford.edu.

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From the best value of 54 fs (NEH) it can be deducted that the beam arrival itself or the Linac to phase cavity RF link are at least that value.

Mysterious Two-State A longer time scale of one minute revealed that the FEH exhibited a peculiar two-state with an 11 sec period, 3 sec one state and 8 sec the other state of about 200 fs separation. Figure 2 top shows this nearly doubled the peak excursions of the transversely deflected beam of the XTCAV on the dump screen BPM. Due to the low frequency it is nearly visible in the archived data, which get sampled every second (Fig. 2 bottom).

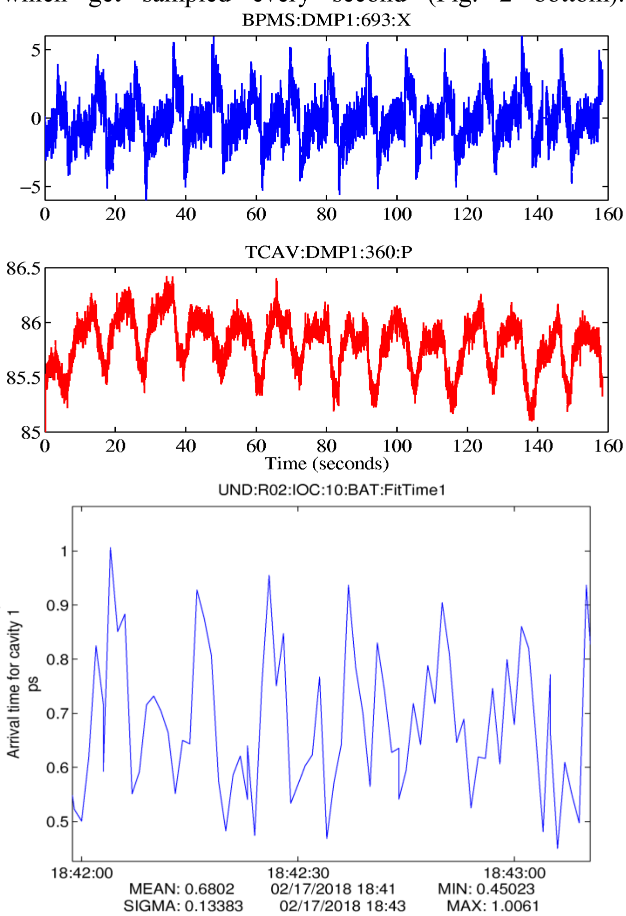

Figure 2: Eleven second period timing two-state with 3 and 8 sec states. The XTCAV deflection (top) has a feedback which corrects the position back to zero making the maximum excursions actually worse (6 mm to 10 mm).

Finding the culprit turned out to be difficult. Two fans on the rack of the FEH timing system were coming closest to the period (8.5 sec on and 9.5 sec off). Then some weeks later by looking at the fit time of the cavities directly it turned out that the frequency had changed. The period was 4 sec, with 1 sec and 3 sec for the different states (Fig. 3). Analysing some older data to figure out when it changed it turned out that there was even a time where the period was only 2 sec with 0.5 sec one way and 1.5 sec the other. An FFT on the archived data (Fig. 4) revealed exactly the time when the changes occurred, but the source wasn't found and mysteriously disappeared, reappearing twice so far for 6 hours with a 2 sec period.

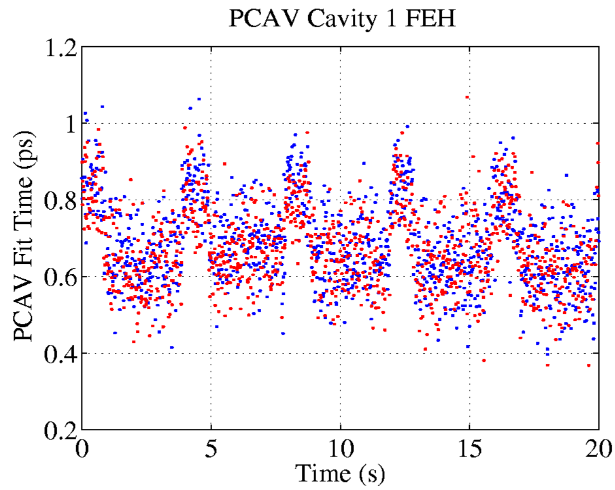

Figure 3: Phase cavity two-state showing the four sec period (1+3 sec). The time slot different (red and blue) is small.

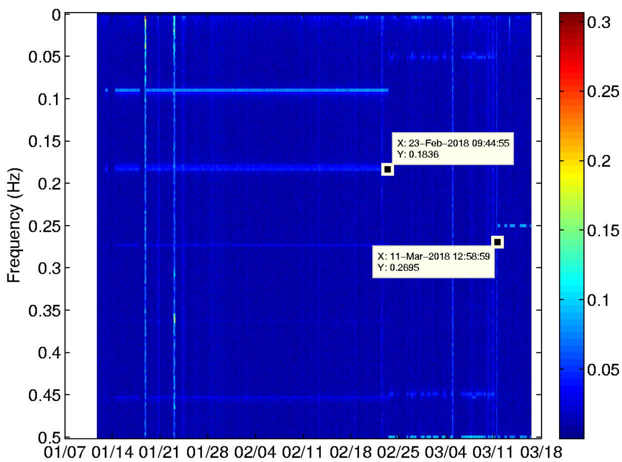

Figure 4: An FFT of the archived fit time revealed exactly when the 11 sec period (0.09 Hz) turns into 2 sec (0.5 Hz, and finally into 4 sec (0.25 Hz).

Active Jitter Reduction

When the 400 fs (at the time) time-slot on the RF reference (FEH) was hurting the XTCAV performance we could counteract it by putting in a 1.5 deg phase offset for one of the RF time-slots.

Since the beam is delayed in the BC2 chicane we can even introduce an energy offset for different time-slots there which will result in different arrival times of the beam. Figure 5 top shows the fit-time histogram for FEH and NEH with the typical double hump distribution for the NEH. After applying a -12 MeV energy offset to one of the two time-slots in BC2 (at 3 GeV) the double humped distribution collapses to one (while the FEH gets wider, Fig. 5 bottom). Figure 6 shows the effect on the electron beam in the Linac and beyond. This would be one way of operation reducing the time slot difference for the NEH users.

Another way is to tell the experimenters in the NEH to analyse the data separately for the two timeslots. This resulted in the "time zero" being a little different for the two sets, but otherwise getting the best timing reference.

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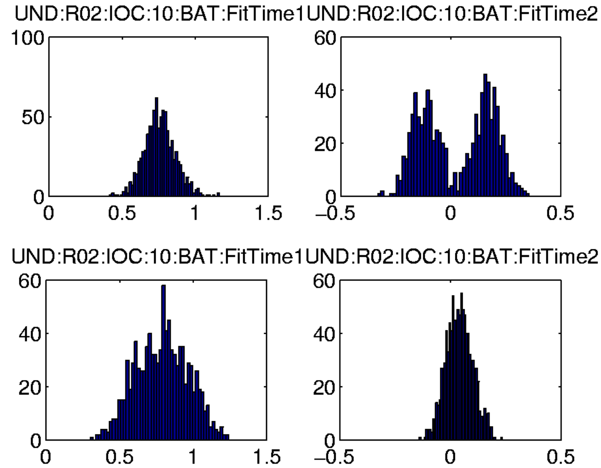

Figure 5: Phase cavity fit-time histogram, FEH (left), NeH (right). The lower plots are after a -12 MeV energy offset in BC2 advances every other beam pulse.

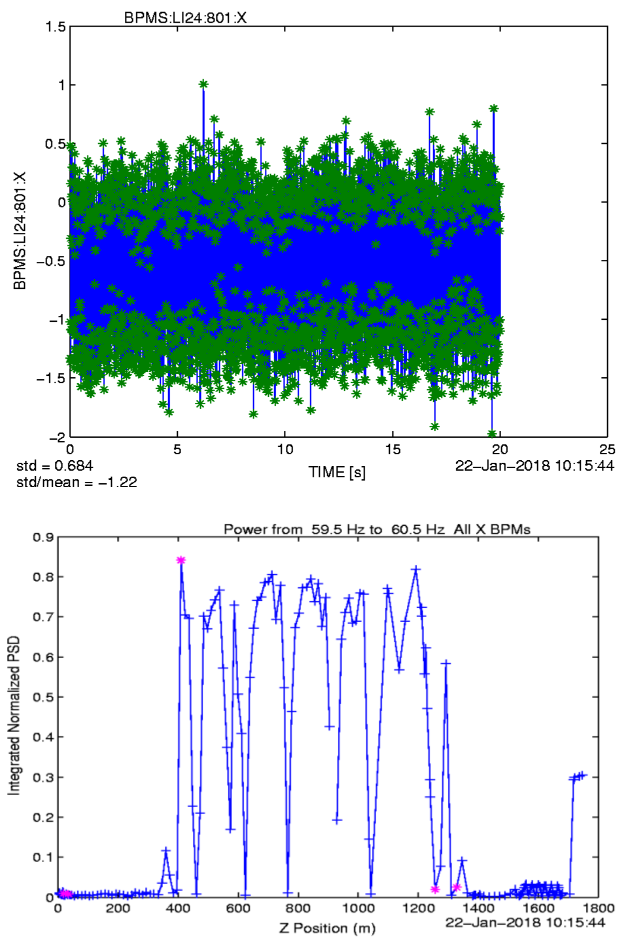

Figure 6: Effect of a -12 MeV time-slot energy offset in BC2 (at 3 MeV) causing a -1.4 mm every other pulse top). Since the leaking dispersion (on purpose to cancel CSR kick) up to 80% of all the jitter downstream is at 60 Hz (bottom). The energy is timeslot corrected at the end of the Linac (Li29/30) so the energy in DL2 (pink dots at $z = 1300$ m) has no timeslot difference. The transverse difference is corrected by a fast feedback just after DL2.

At the experiments "good" timing stability is about 290 fs (FWHM) or 125 fs rms, while with another laser it wanders around up to 1000 fs (peak to peak) or 250 fs rms pointing to stability issues at the lasers [5].

LASER STABILITY

The injector laser system is equipped with two lasers. While one laser (Coherent 1) is quite stable with 35 fs (Table 1), the second laser has a strong 20.35 Hz line (and a smaller 59 Hz line) causing 95 fs jitter. The 20.35 Hz line comes from the "power track dither" of the Carrier Envelope Phase (CEP) "stabilization" system. It is visible on the beam especially in BC1 where 300 fs (peak to peak) causes about 300 µm variation. It is about 65% of all the measured jitter (Fig. 7). Luckily this laser jitter and the Gun phase jitter (2[nd] biggest) are compressed by a factor of ten and therefore barely visible downstream.

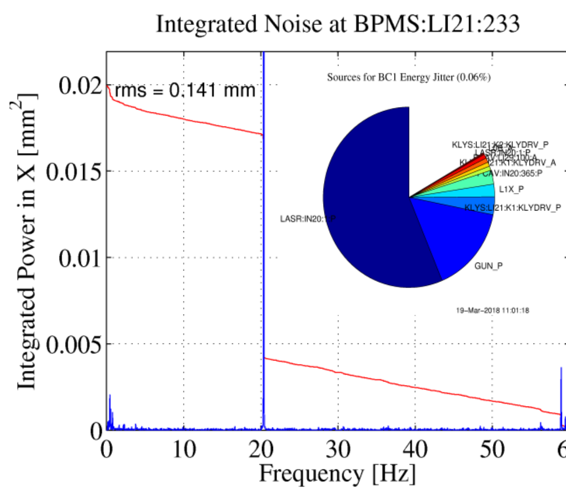

Figure 7: Bunch Compressor 1 (BC1) BPM FFT showing that 65% of the measured energy jitter is caused by the laser timing jitter.

CONCLUSION

The timing stability of the beam can be as good as 50 fs still shy of the 30 fs the high power RF can achieve. Often additional sources which haven't identified make it worse.

REFERENCES

[1] F.-J. Decker *et al.*, "Increased Stability Requirements for Seeded Beams at LCLS", in *Proc. FEL'13*, New York, NY, USA, Aug. 2013, paper WEPSO10, pp. 518-521.

[2] F.-J. Decker *et al.*, "Improving and Maintaining FEL Beam Stability of the LCLS", in *Proc. IPAC'14*, Dresden, Germany, Jun. 2014, pp. 2943-2945, https://doi.org/10.18429/JACoW-IPAC2014-THPRO035

[3] L. Wang *et al.*, "Energy Jitter Minimization at LCLS", in *Proc. FEL'15*, Daejeon, Korea, Aug. 2015, paper TUP070, pp. 523-529.

[4] J. Frisch, "Beam Arrival Time Monitors", in *Proc. IBIC'15*, Melbourne, Australia, Sep. 2015, pp. 256-262, https://doi.org/10.18429/JACoW-IBIC2015-TUALA01

[5] S. Boutet, private communication.