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TWO AND MULTIPLE BUNCHES WITH THE LCLS COPPER LINAC*

F.-J. Decker†, W. Colocho, A. Halavanau, A.A. Lutman, J.P. MacArthur, G. Marcus, R.A. Margraf, J.C. Sheppard, J. Turner, S. Vetter, SLAC, Menlo Park, CA, USA

Abstract

Two, four, and even eight bunches were accelerated through the copper linac. Two and four bunches were delivered successfully to photon experiments in both the hard (HXR) and soft (SXR) LCLS x-ray lines. In this paper we will concentrate on the more challenging issues, such as: the BPM deconvolution for both bunches, RF kicks at longer separations, tuning challenges, bridging the communications gap between the photon and electron side, the lower bunch charges for the eight bunch case, and rapid timing scans over several ns. We will describe some of the developed solutions and plans for the rest.

INTRODUCTUION

Two bunch running is now quite well established, only longer time separation of 220 ns and beyond are more problematic. For a general reference, see [1].

FOUR AND EIGHT BUNCHES

Eight bunches, 0.7 ns apart were accelerated in the LCLS copper linac and brought onto the dump screen (Fig. 1). The differences are quite obvious and come from the different intensities from the laser pulses onto the gun cathode.

Multi-Bunch Generation

The Multi-Pulse Pulse-Stacker (MPPS, see Fig. 2 in [2]) splits, delays and combines light pulses of two laser (Coh1, Coh2) into four pulses each. In Figure 1 the order is: Coh1 B1+B2+B3+B4 then Coh2 B1+B2+B3+B4. Bunches 3 and 4 from each laser have lower intensity and Coh1 was lower than Coh2. Lower charge bunches get off the cathode faster and in the end get compressed more. The charges were quite far away from equal (12.5% each). The deviations from that number in percent were: -6, +7, -29, -26, +22, +40, -6, -2, making the 6th bunch about twice as intense as the 3rd one. The average charge of 60 pC was about a third of the typical intensity.

Charge Sensitivity

Even though the phase change due to charge is quite small the effect on peak current and therefore CSR kick is large, see Fig. 2 and 3. Besides the initial difference in charges which were caused by a not ideal 50/50 splits, it was recently found that some of the mirrors for the delayed bunches were clamped so hard that the mirrors deformed and caused the delayed laser pulses to a more elliptical than round shape and therefore causing some intensity loss due to apertures. For two bunches a charge difference can be used for tuning.

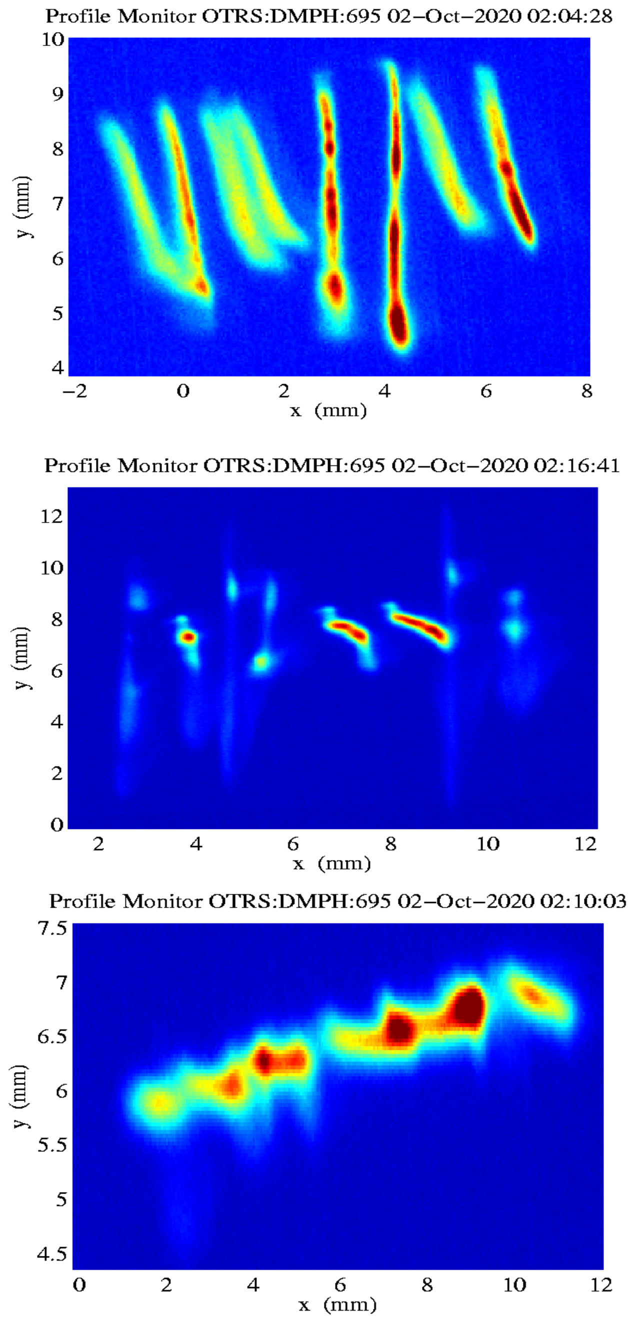

Figure 1: Eight bunches 0.7 ns apart on the OTR dump screen. The time resolving transverse cavity XTCAV was detuned in temperature so the eight bunches don't overlap in time (horizontal). The vertical dimension is proportional to energy. All bunches are over-compressed (top), while for the middle the compression was reduced (-32° to -30°), so bunches B2, B5 and B6 were under-compressed. At the bottom (at -29° in L2 phase) all are under-compressed. The energy slope along the bunches of about +2% is real. It was not corrected at the time.

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† Decker@SLAC.Stanford.edu

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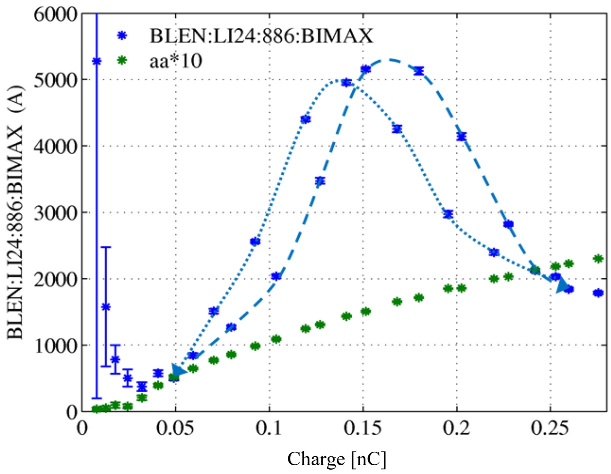

Figure 2: BC2 peak current (blue) [and BC1 *10] versus charge. The time separation (dotted versus dashed) comes from the fact that the scan was done in "zig-zag" mode (going up and down) so a small phase drift during a scan can be easily detected since feedbacks had to be off.

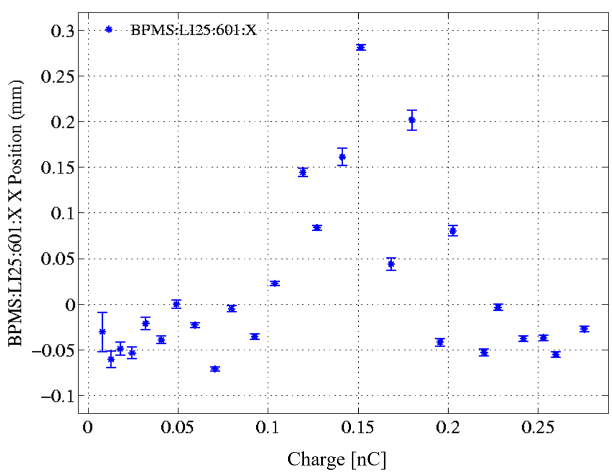

Figure 3: CSR induced transverse kick causing a trajectory change up to 0.3 mm after BC2, or about six times the RMS beam size (Data form 28-Jul-2021 11:03:18).

Reduced Tuning Parameters

For four and even more for eight laser pulses the tuning parameters are restricted compared with two pulses. The easiest way to see this are the delays. Timing of the two lasers plus one delay stage gives three parameter for four delays. This is similar for intensities, therefore one bunch cannot be adjusted in time or charge or direction. For the eight pulse case we get an additional delay stage, so four parameter for eight bunches. They should be equal "automatically", but typically they are not.

TWO BUNCHES WITH BIG SEPARATION

There are three main issues concerning two bunches with long separation of >200 ns. A) They experience different RF kicks and therefore have different trajectory in the undulator. How we solve that with kickers is described in another paper [3]. B) Equal energies for two bunches can be achieved by timing the SLED RF pulse, see Fig. 4 (blue). It gets trickier for four or more bunches and RF manipulation techniques like in [4] have to be deployed. C) RF phase changes of a few degrees when the SLED pulse is early are quite a concern and are the cause that the second pulse is typically further compressed and therefore has more peak current, see Fig.4 (green).

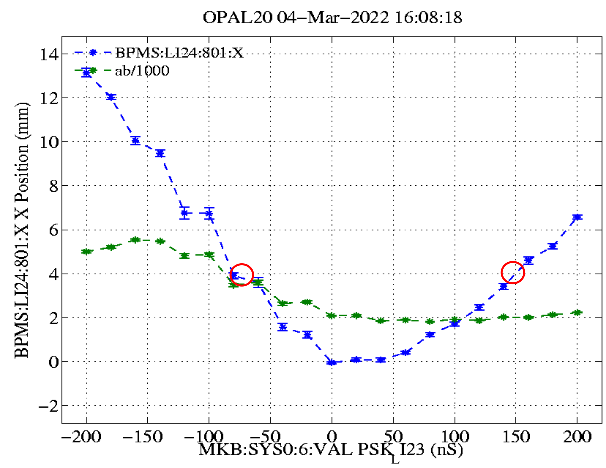

Figure 4: Energy (blue, inverted) and peak current (green, in kA) at BC2 versus SLED RF timing. While there are two points with the same energy (red circles, 218.5 ns apart) the phase of L2 is different by a few degrees and therefore the peak compression is quite different by a factor of two.

Phase Change during SLED Pulse

The phase change can have different causes. An obvious cause can be an RF with different phase entering or exiting on purpose, by a mistuned SLED cavity, or a different modulator high voltage and therefore a different phase. But even with perfect phase control the sudden change in amplitude due to the 180° phase jump which creates the SLED pulses causes different frequencies, which travel with different speeds along the three meter accelerating structure or disc loaded waveguide (DLWG). This causes a changing phase when the peak amplitude starts exiting the DLWG [5]. This effect could be counteracted by an I and Q waveform control of the RF allowing an independent amplitude and phase control.

Signals Used for Tuning

The Beam Positions Monitors (BPM) show the trajectory of the beam through the accelerator, the undulator and finally to the dump. For two bunches the normal BPM system shows a vector sum, so a special deconvolution software was developed. Since there were changes for the undulator BPMs and their digitizers another quick way was to just time every other BPM electronics so that they showed mainly only one bunch (Fig. 5).

After the bunches are overlapped enough (<0.1 mm) the fine tuning is done using the gas detector or even more preferred a signal closer to the experiment. Going through a monochromator and detecting the two bunches with a fast diode their intensities are plotted versus electron energy and can therefore be aligned in energy and equalized in intensity (Fig. 6).

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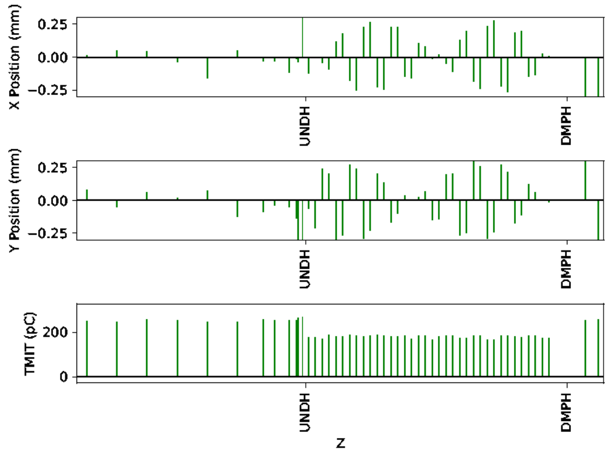

Figure 5: BPM orbit display. In the undulator the timing of for the BPM digitizer gate was setup to only measure one or the other bunch when they were 218.5 ns apart. This gave enough signal to tune them to have finally the same orbit.

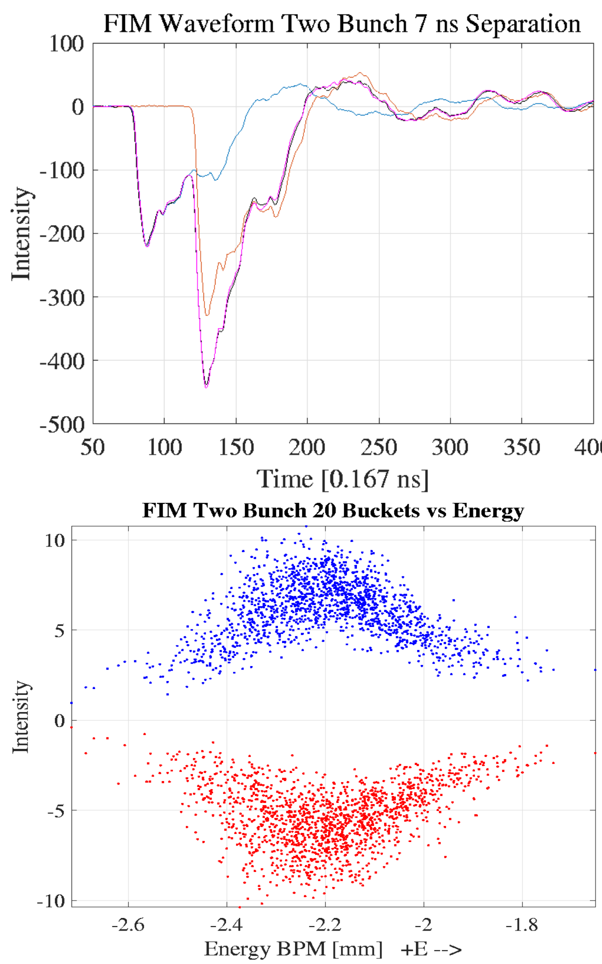

Figure 6: Fast Intensity Monitor (FIM) signal de-convoluted for two bunches 7 ns apart (top). The individual intensities are then plotted versus the electron beam energy (bottom). The successful data transfer from the photon side to the accelerator side made this plot possible in real time for tuning.

Rapid Timing Scan

A rapid timing scan of the bunch separation over a few minutes could be done in the 38 to 54 ns range where wakefields are weak and RF kicks still quite similar. A whole oscillation period of a diamond crystal could be measured.

CONCLUSIONS AND FUTURE STEPS

There are a few parameters which have to be right for multiple bunches and two bunches to create equally good x-ray laser pulses in the undulator. They are mainly the trajectory in the undulator and the peak current. The trajectory gets influenced by wakefields, RF and CSR kicks, and launch conditions, but can be controlled by four fast kickers (two already installed). The final peak bunch current is determined by the timing of the bunch with respect to the RF phase in L2. A difference can come from the initial beam arrival time into L2 caused by different charges, different Schottky phases (laser phases), and/or phase differences of the injector stations, often the L1X phase difference is used for tuning. But also the phase of L2 is different on both sides of the peak amplitude of the SLED pulse.

Equal charges are critical for multiple bunches (>2). Getting longer and maybe variable delays for multiple bunches is an even more significant challenge. The split and delay on the laser table could have a longer fixed path and therefore delay, but at some point the energies will be too different and an RF waveform control for amplitude and phase has to be implemented. Since the split and delay uses some paths twice for the four bunch mode, and some even four times for eight bunches, the tuning parameters are reduced. This should have advantages like one setup for four, but are different due to launch conditions (reflected versus transmitted or laser profiles).

The two bunch setup has all the tuning parameters available due to the use of two different lasers. Different separation delays have unique challenges. From 0.35 ns to about 10 ns wakefield kicks dominate. The BPM vector sum is pretty low at (n+1/2) * 7 ns, so these delays should be avoided when running with beam based feedbacks. Phase variations in L2 at long delays need to be controlled.

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