ISBN: 978-3-95450-214-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2021-TUPAB083

DUAL ENERGIES IN THE LCLS COPPER LINAC*

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Abstract

For LCLS-II two undulators were installed at SLAC, one for soft and one for hard x-rays. Before the superconducting linac gets turned on the copper linac is providing beams at 120 Hz to these two beam destinations. The 120 Hz can be split in many different ratios between soft and hard via a pulsed magnet. To get an optimized beam for the quite different photon energies the pulsed linac components like modulators and RF can provide many different beam parameters, mainly energies and bunch lengths for the two undulator lines. How this was implemented with timing setups of triggers and finally after the split the necessary matching of the transverse phase space will be discussed.

PULSED BEAM MANIPULATION

The two undulators have their optimal intensity performance around 10-12 GeV for the Hard X-Ray line (HXR), and 4-6 GeV for the Soft X-Ray line (SXR). Since the copper linac is a pulsed at 120 Hz, each pulse can have different trigger assignments and the RF can have different amplitudes and phases. This enables beams with different energies like in the past [1], different bunch lengths, and different charges at a few different rate ratios, for example one beam can have 0, 1, 10, 30, or 60 Hz, while the other beam gets the rest of the 120 Hz.

Beam Energies

Figure 1 shows the energy profiles along the linac, where both beams are accelerated equally up to BC2 (Bunch Compressor 2) at BPM # 48. After that, triggers to activate the klystrons are set differently for the two beams (Fig. 2), and near the end (LI29 / LI30) an energy feedback adjusts phases pulse by pulse to set both beams to their desired final energy.

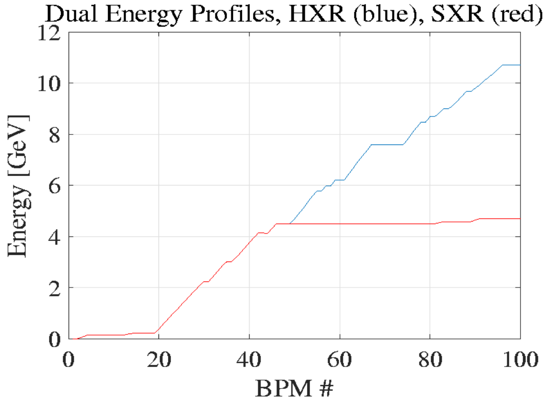
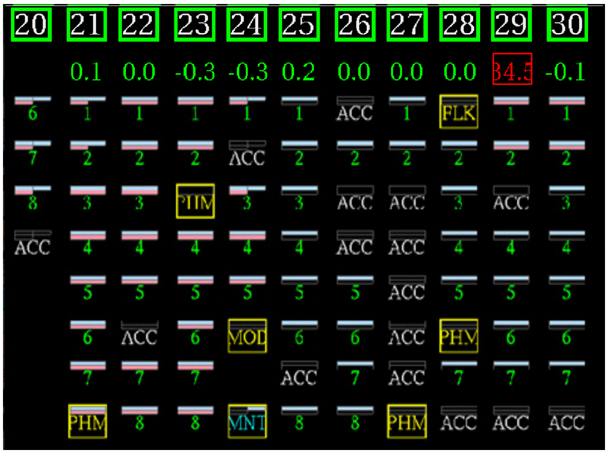


Figure 1: Energy profiles along the linac.



20	21	22	23	24	25	26	27	28	29	30
	0.1	0.0	-0.3	-0.3	0.2	0.0	0.0	0.0	34.5	-0.1
6	1	1	1	1	1	ACC	1	FLK	1	1
7	2	2	2	ACC	2	2	2	2	2	2
8	3	3	PTIM	3	3	ACC	ACC	3	ACC	3
ACC	4	4	4	4	4	ACC	ACC	4	4	4
	5	5	5	5	5	5	ACC	5	5	5
	6	ACC	6	MOD	6	6	ACC	PHM	6	6
	7	7	7		ACC	7	ACC	7	7	7
	PHM	8	8	MNT	8	8	PHM	ACC	ACC	ACC

Figure 2: Klystron overview panel showing the status of all the LCLS klystrons. Whether they are on for the beam going to the hard x-ray line (blue) and/or soft x-ray line (red) is indicated by horizontal, colored bars, in this case 10.7 and 4.7 GeV in Dual Energy Mode. The yellow boxes indicate problems, like PHM (Phase Mean), or Modulator maintenance. Stations with ACC are pulsed after beam time not currently used for acceleration.

RF Phases and Amplitudes

The RF phases and amplitudes in the longitudinal feedback (and a few other stations) can be set by four different data slots (DS). Originally there were two controls, one for each of the 60 Hz time slots (TS) that comprise the 120 Hz beam rate. It was envisioned that the 30 Hz running of FACET would affect the LCLS beam, so each 60 Hz time slot was divided into two 30 Hz data slots, but that turned out to be much less of a problem, so the data slots were modified to two 60 Hz time slots and two different beam destinations (Fig. 3).

Set STATIC DATA:		Set Value	Offset	Master Set Value
HXR XTCAV MUX	DS0:	95.6330	0.0000	95.633
	DS3:	95.6330	0.0000	
SXR XTCAV MUX	DS1:	81.0727	0.0000	81.006
	DS2:	81.0727	0.0000	

Figure 3: XTCAV (X-band Transverse deflecting Cavity) with its different phase setting for HXR (TS 4 and 1) and SXR (TS1 and 4) with two separate master set values.

The longitudinal feedback is currently configured to have only one master value (to be upgraded soon), so the values for the SXR line are the "difference" to the HXR

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* Work supported by U.S. Department of Energy, Contract DE-AC02-76SF00515.

line. This is often very confusing and gets explained here by an example where the SXR line is at 4.1 GeV, or -0.4 GeV below the 4.5 GeV at BC2. The HXR line is 5.5 GeV above that (2.5 + 3.5·cos(31)), or at 10 GeV. The offset and set value for the SXR ended up confusingly at -4.05 GeV and 1.45 GeV. It makes sense when looking at the final SXR phase of -107.45 deg, but instead of multiplying the cosine with its energy of 1.33 GeV to get -0.4 GeV, the term 3.5 GeV · cos(-107.45) gives -1.05 GeV. So, it looks to the feedback as if the SXR line is -1.05 GeV below 2.5 GeV at 1.45 GeV.

The energy set point in BC1 which controls the amplitude of the RF station L1S can be used to create different charges downstream since two collimator jaws in the chicane clip the charge typically from 250 to 180 pC (horn-clipping). Lower charges of 80 pC or even 30 pC were achieved, see Fig. 4 and Table 1.

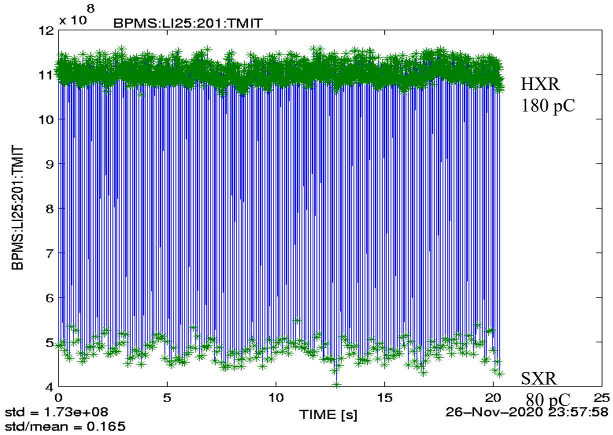

Figure 4: Cutting charge in BC1 for HXR the typical 250 to 180 pC, while for SXR it is down to 80 pC.

Table 1: Charge Reduction Effects

BC1 Energy set point [MeV]	0	-5	-7
Charge [pC]	180	80	30
L1S Ampl. [MeV]	110	105	103.5
BC1 Orbit [mm]	0	+5.2	+7.4
BC1 Peak Current [A]	195	130	40
BC2 Peak Current [A]	3200	1700	800

Beam Rate Control

The SLAC timing system allows many possible timing setups of the different 120 Hz pulses with six 32 bit modifier masks as part of the timing pattern. Those modifiers, inclusion and exclusion masks, are packaged in event codes and individualized event definitions. The use of beam codes for different beam destinations (a scheme used through most of SLAC's operation) was resurrected with beam code 1 used for HXR and beam code 2 for SXR, so triggers can be setup easily for one or the other destination.

DC BEAM MANIPULATION

Steering with direct current (DC) correctors and matching with DC quadrupoles can be done where the energy of the two beams is sufficiently different and/or after the branching of the two beams into their respective beam lines.

Beam Steering

The difference orbit of the two beams at the end of the linac turned out to be quite big (> 1 mm) due to RF kicks [2] and required initially some lengthy interventions. The easiest to understand is the use of closed 3-corrector local bumps, closed for one beam energy, but open for the other. The "three correctors" can be also far apart using set point changes of one transverse feedback to create an oscillation, and letting the downstream feedback close it. Finally, we developed a dual energy steering code which uses the effects. It should be mentioned that "klystron voodoo" plays a role too, trying different combinations of klystrons to identify those with a strong transverse RF kick and turning them off or on for both beams. Excursions up to 1 mm can be reduced after the branching point, see Fig. 5.

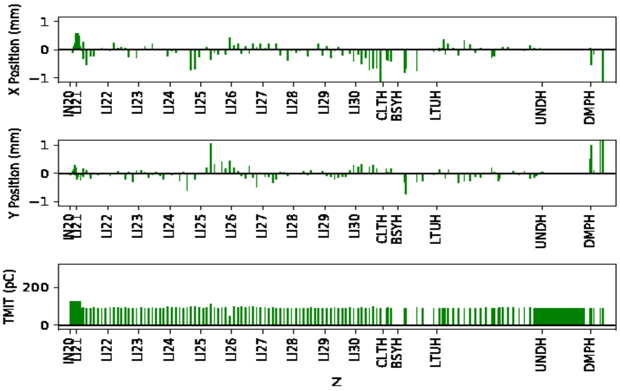

Figure 5: HXR orbit with excursions up to 1 mm approaching the branching point (CLTH). The HXR beam was setup after the SXR beam at design quadrupole strengths and steered down to 0.3 mm.

Betatron Matching

The betatron functions of the two beams have to be matched into the design optics of the downstream beam lines. This can be done in many different ways. Typically we choose the design lattice in the linac for the primary program (HXR or SXR) and match the lattice for the other beam line with four quadrupoles after the branching point. The straight HXR line is easier to match and up to a factor 2.5 in energy was successfully achieved with this predictive match (Fig. 6). The SXR starts with a bend and dispersion in the CLTS (Copper Linac To Soft) line, so the matching quadrupoles are a little further downstream. This creates beta beats up to 8,000 m in the CLTS line and beta matching with an energy difference only below a factor of 2 were successful. The predictive match still uses the design energy profile in the linac, so it just gets close and further quadrupole tuning is necessary. When using the real energy profile (as opposed to design) a better match is expected.

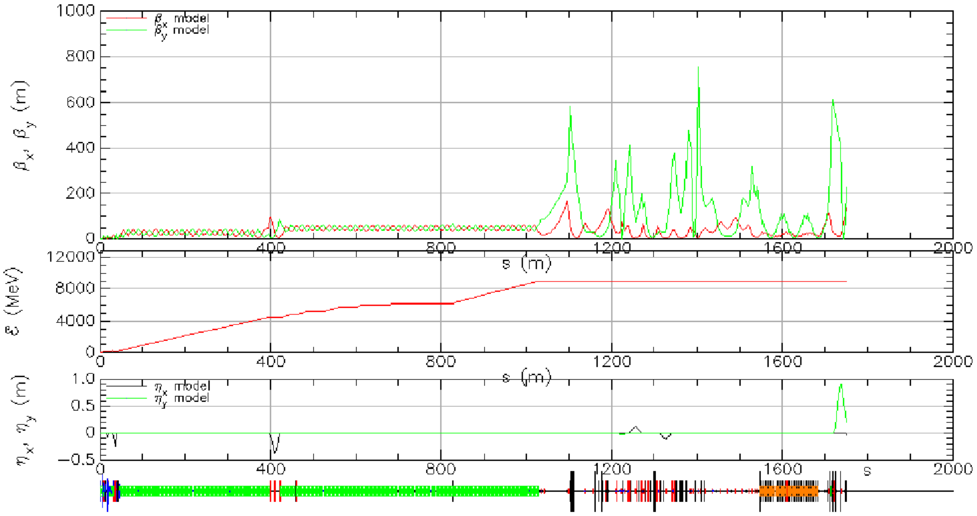

Figure 6: Betatron lattice before implementing the predictive match for the HXR line. This gets the betatron functions to design values beyond s = 1200 m.

Beam Tuning

It turned out that some of the beam tuning done in the common area of both beams by Sector 26 quadrupoles is still an option for both beams since the SXR beam is less sensitive by about a factor of two (Fig. 7). Other tuning tools can be used by the pulsed devices and after the branching point.

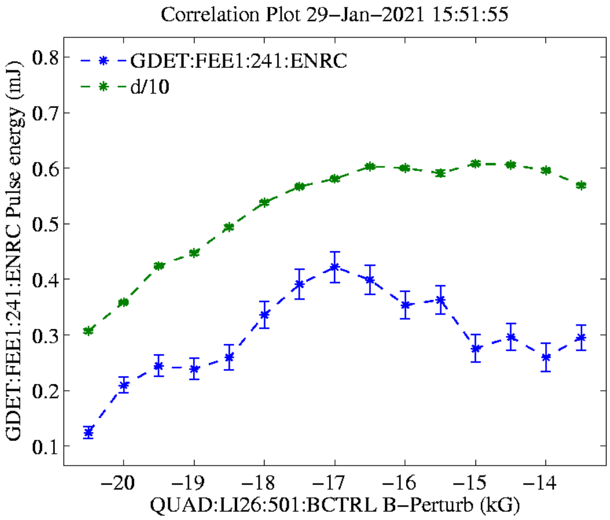

Figure 7: Tuning both beams with LI26 Quads. → GDET (blue) in HXR is typically more sensitive, while the GMD (green divided by 10) from SXR is up to 6 mJ and less sensitive.

Oddities

There are still a couple of strange behaviours trying to get the two beams running on a system which was using one beam for ten years. When setting a peak current offset of say 500 A you get twice as much, and when doing an energy Vernier (small offset) you get half of the request. Another one is in the Machine Protection System. Beam loss monitors in HXR pick up losses from mismatched SXR beams, which (unfortunately) trips the HXR line off. The machine protection system was not designed for this kind of case in mind.

CONCLUSION

The dual energy setup in the LCLS copper linac has enabled the delivery of hard and soft x-rays simultaneously using close to the optimum electron energies. The rate split is typically 110 to 10 Hz. It was achieved using different trigger times of pulsed devices, and differently settable phases and amplitudes of RF devices.

REFERENCES

[1] F.-J. Decker *et al.*, “High Power Beam at SLAC”, in *Proc. IEEE Particle Accelerator Conference (PAC 2001),* Illinois, USA, July 2002, paper SLAC–PUB–9359.

[2] A. Margraf, F.-J. Decker, G. Marcus, and Z. Huang, “Measurement and Correction of RF Kicks in the LCLS Accelerator to Improve Two-Bunch Operation”, presented at the 12th Int. Particle Accelerator Conf. (IPAC'21), Campinas, Brazil, May 2021, paper TUPAB110.