LCLS-II Technical Note

Polarization Control for the LCLS-II SXR Undulator Line

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James MacArthur, Gabe Marcus, Heinz-Dieter Nuhn

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The Linac Coherent Light Source II (LCLS-II) construction project at the SLAC National Accelerator Laboratory is designed to generate linearly polarized, intense, high brightness x-ray pulses from planar variable-gap undulators. The planar undulator design lacks polarization control, which is of great importance for soft x-ray experiments. The LCLS-II project provides space between the last undulator and the x-ray beam transport section to add DELTA undulators for polarization control. The DELTA [i] undulator segments provide full control of the polarization degree and *K* value through row position adjustments. Used on their own, they produce fully polarized spontaneous radiation in the selected state (linear, circular or elliptical). To increase the output power by orders of magnitude, the electron beam will be micro-bunched by 5-15 upstream LCLS-II undulator segments operated in the linear FEL regime. This micro-bunching process produces moderate amounts of horizontally linear polarized radiation. Depending on the polarization mode of the DELTA undulator, the horizontally polarized radiation can provide a seed for the FEL process or an unwanted polarization component. This unwanted radiation component can be greatly reduced by the reversed taper configuration, which has recently been suggested by E. Schneidmiller [ii]. Performance estimates have been obtained through FEL simulations with the 3D FEL code Genesis 1.3 [iii] in time dependent mode, predicting both the final power and degree of circular polarization resulting from the use of DELTA undulators in an afterburner configuration following standard planar undulators in standard and reverse taper modes.

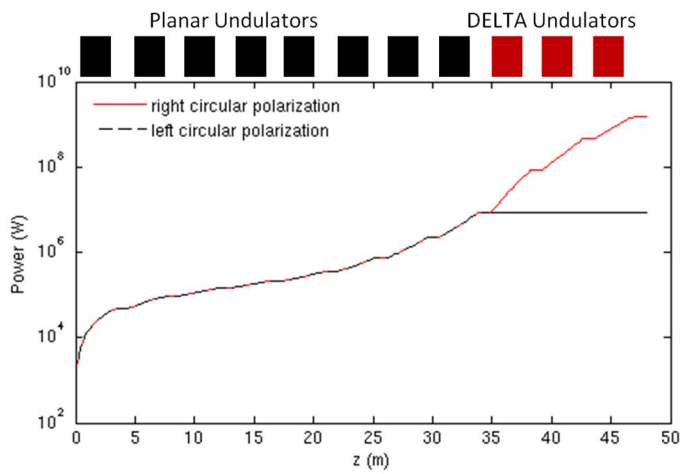

Figure 1: The power growth in left and right circular polarization modes is plotted against distance along the undulator line. The DELTA undulators operate in right circular mode in this simulation.

The simulations use the canonical LCLS-II beam parameters at the undulator entrance, i.e., electron energy of 4 GeV with an energy spread of 0.4 MeV, a transverse emittance of 0.4 µm, and a peak current of 1 kA. Simulations were performed at radiation wavelengths of 1 and 2 nm. The first part of the undulator line consists of variable *K* planar undulators, which microbunch the electron beam. The microbunched beam is then sent into a line of 1, 2 or 3 DELTA undulators. The DELTA undulators were simulated in the circular mode. Care was taken to decompose the linearly polarized radiation from the planar undulators into the right-left circular polarization basis in order to properly seed the DELTA undulators with the correct circular radiation component. An example of this undulator configuration and the resulting power growth of both circular components is presented in Figure 1.

The simulations show that there is a tradeoff between total power and degree of circular polarization. The total power is optimized by increasing the number of plane polarized undulators preceding the DELTA undulator line, while the degree of circular polarization is optimized by shortening the line of plane polarized undulators to stop well before saturation. This tradeoff is explored at 1 and 2 nm in Tables 1 and 2. The degree of circular polarization is defined in terms of the Stokes parameters S_3 and S_0,

$$DOCP = \frac{S_3}{S_0} = \frac{I_R - I_L}{I_0},$$

where I_R and I_L are the intensity of right and left circular radiation, and I_0 is the total intensity. This number is reported and compared to the power in the tables below. A variable number of planar undulators and DELTA undulators is explored, and optimal configurations are in bold.

The results of reverse taper simulations are presented in Tables 3 and 4. In these simulations, a linear reverse taper was applied to the planar undulator line preceding the DELTA undulator line. A continually increasing detune of 0.1% and 0.2% per undulator was applied to the undulator line in the 1 and 2 nm modes, respectively. The reverse taper suppresses the FEL power while still amplifying bunching near the frequency resonant at the start of the undulator line. The DELTA undulators are tuned to the resonant undulator parameter, and the FEL power grows rapidly in the circular mode. This technique decreases the number of DELTA undulators required to reach a high degree of circular polarization near saturation. However, locating the ideal reverse taper slope and undulator length presents an operational challenge.

Table 1: Simulation Results in Regular Mode at λ_r=1 nm.

	1 x DELTA	2 x DELTA	3 x DELTA
7 Planar	0.02 GW/ 0.80	0.12 GW/ 0.96	0.58 GW/ 0.99
8 Planar	0.09 GW/ 0.81	0.46 GW/ 0.96	1.55 GW/ 0.99
9 Planar	0.38 GW/ 0.80	1.46 GW/ 0.95	2.92 GW/ 0.97
10 Planar	1.24 GW/ 0.76	3.00 GW/ 0.90	3.60 GW/ 0.92

Table 2: Simulation Results in Regular Mode at λ_r =2 nm.

	1 x DELTA	2 x DELTA	3 x DELTA
5 Planar	0.02 GW/ 0.89	0.16 GW/ 0.99	1.35 GW/ 1.00
6 Planar	0.13 GW/ 0.90	1.00 GW/ 0.99	3.41 GW/ 1.00
7 Planar	0.60 GW/ 0.90	2.92 GW/ 0.98	4.65 GW/ 0.99
8 Planar	2.69 GW/ 0.83	4.96 GW/ 0.91	4.38 GW/ 0.90

Table 3 Simulations Results in Reverse Taper Mode at λ_r = 1 nm

	1 x DELTA	2 x DELTA	3 x DELTA
12 Planar	0.71 GW/ 0.98	2.42 GW/ 0.99	4.37 GW/ 1.00
13 Planar	0.87 GW/ 0.98	2.71 GW/ 0.99	4.64 GW/ 1.00
14 Planar	1.15 GW/ 0.98	3.05 GW/ 0.99	4.72 GW/ 1.00
15 Planar	1.02 GW/ 0.98	2.74 GW/ 0.99	4.56 GW/ 1.00

Table 4: Simulation Results for Reverse Taper Mode at λ_r = 2 nm

	1 x DELTA	2 x DELTAs	3 x DELTA
10 Planar	1.90 GW/ 0.99	6.02 GW/ 1.00	6.85 GW/ 1.00
11 Planar	2.53 GW/ 0.99	6.38 GW/ 0.99	7.17 GW/ 1.00
12 Planar	3.11 GW/ 0.99	6.69 GW/ 0.99	7.33 GW/ 0.99
13 Planar	3.15 GW/ 0.99	6.38 GW/ 0.99	6.92 GW/ 0.99

Currently, techniques of spatially separating the linear polarized background component from the circular components are being developed providing potentially full polarization with as little as one polarization control segment. Table 5 lists key parameters of the Delta undulator:

Table 5: Key Parameters of the Delta Undulator

Undulator Period	39	mm
Magnet Block Height	30	mm
Magnet Block Width	25	mm
Row Position Adjustability	±20	mm
K_{max}	5.48	

[i] H.-D. Nuhn et al., "R&D" Towards a Delta-Type Undulator for the LCLS", SLAC-PUB-15743

[ii] E.A. Schneidmiller, M.V. Yurkov, "Obtaining high degree of circular polarization at X-ray FELs via a reverse undulator taper", arXiv:1308.3342 [physics.acc-ph]

[iii] S. Reiche, "Genesis 1.3: A Fully 3D time-dependentFEL simulation code," Nucl. Instr. and Meth. A 429 (1999) 243