Laser Heater for LCLS

Implementation

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Design Goals

- Introduce energy spread by rapidly modulating the electron beam energy along the bunch, $\Delta E/E_{\text{rms}} \sim 4 \times 10^{-4}$ at 135 MeV, via the FEL interaction with a laser beam.

- Optionally provide a transverse variation of the energy modulation on the scale of the electron beam size.

- Use leftover 795 nm IR light from Drive Laser.
FEL Energy Modulation Mechanism

Resonance condition

- 2 phase slip per undulator period

\[ \square[\dot{\Delta}] = \frac{13.056 \square[cm]}{E^2[GeV]} \left(1 + \frac{K^2}{2}\right) \]
Design Issues

- Undulator Parameters
- Laser Power Required
- Laser and Optics
  - Large laser spot
  - Small laser spot
- Alignment Tolerances
- Layout
- Diagnostics and Tune Up
- Design is still in flux
Undulator Optimization

- Shortest period results in least laser power
- Used Elleaume parameterization for hybrid PM (with iron)
- Gap set at $\approx 1\ 1/8\ inches$ to clear 1 inch chamber and match resonance condition. Vary period to get resonance
- Result: undulator period = 5 cm
Laser Power Required

<table>
<thead>
<tr>
<th>Energy gain</th>
<th>73.6 [keV]</th>
</tr>
</thead>
<tbody>
<tr>
<td>rms energy change</td>
<td>52.0 [keV]</td>
</tr>
<tr>
<td>rms relative energy spread @ 135 MeV</td>
<td>3.9E-04 rms</td>
</tr>
<tr>
<td>relative energy spread @ 4.54 GeV</td>
<td>5.0E-05 rms</td>
</tr>
</tbody>
</table>

**Magnet Calculation**
Elleaume parameterization hybrid with Fe poles

**Input**
- a_coef: 3.381
- b_coef: -4.73
- c_coef: 1.198
- gap: 2.86 [cm]
- Undulator period: 5 [cm]
- Radiation Wavelength: 795 [nm]

**Output**
- B_peak: 0.334 [T]
- K_undulator: 1.562
- K_res: 1.562
- gap/period: 0.572

**Laser Beam Parameters**
- power: 65 [MW]
- width: 3.0 [mm]

Formula agrees with Saldin example for TTF
Undulator Tuning Sensitivity

Energy Gain

K parameter

LCLS Linac Coherent Light Source
Stanford Synchrotron Radiation Laboratory
Stanford Linear Accelerator Center

LCLS Injector Review, 3 Nov 2003
Laser Heater System

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### Laser and Optics

#### Large spot limit
- $w_0 = 3$ mm, $Z_R = 36$ m, $65$ MW, $20$ ps, $790$ nm
- Effective undulator length = physical undulator length = $0.5$ m
- Alignment tolerance $\sim \pm 1.0$ mm

#### Small spot limit
- Spatial modulation of laser spot on the scale of the electron beam size $\sim 100$ microns is desired
- Rayleigh length = $40$ mm for $w_0 = 100$ microns, so effective undulator length is limited to $\sim 8$ cm
- Required laser power still needs to be worked out
- Alignment tolerance is $\sim 10$ microns
Alignment Tolerance, Large Spot

beamsigma \sim 100 \mu m
L\text{undulator} = 0.5 \text{m}
laser offset @ 90\% \text{Field} = 1004 \mu m
misalignment tolerance \sim \pm 1 \text{mm}
Small Spot Scheme

variable focal length \(\pm 2.5\) m

\(w_0 \sim \sigma_e \sim 100\) \(\mu m\)

electron beam

undulator

\(w_0 = 3.0\) mm is obtained by changing focal length, keeping 3 cm beam at mirror

special mirror
Laser Heater System

Laser Room

Accelerator Tunnel

- 10 ps electron pulse
- variable focus optics
- Transport and Steering, net 50% loss

- ~65 TW, 20 ps, 1.3 mJ

- OTR
- Undulator

- Laser Diagnostics
  - Quadrant detector, power, energy, camera, timing diode

Electron Beam Diagnostics

- 10^{-4} - 10^{-5} Energy Resolution
**Laser beam**
- continuously measure beam position and power level at exit of chamber
  - quadrant detector, camera, Joule meter

**Electron beam**
- detect energy spread signal to align laser beam to electron beam
  - <= 50 keV = 4x10^{-4} @ 135 MeV, i.e. 10^{-5} - 10^{-4} energy resolution
  - on/off shutter on laser beam

**Tune up procedure**
- tune up with 3 mm spot using OTR’s and spectrometer
- gradually reduce spot size to 0.1 mm, re-steering as necessary.
- remote steering and focussing control needed.
After substantially more investigation and additional demands, the laser heater system still looks feasible. It requires:

- reasonable laser power from the drive laser
- a small straightforward undulator
- ordinary optics and laser instrumentation, except for one specialized mirror
- small modifications to injector vacuum chamber

Principle remaining uncertainties:

- electron beam / laser interaction in the small spot case
  - laser power
  - spatial modulation
- diagnostics to tune up overlap of laser and electron beams
- optical layout
Extra Slides

- emittance growth from dispersion
- transverse momentum
- laser / electron beam angle effects
Emittance Growth from Dispersion

What is maximum dispersion such that the emittance growth is less than 1%?

\[ \hat{\epsilon} = \frac{\hat{\epsilon}}{\epsilon} = 3.9 \times 10^{-4} \]

\[ \hat{\epsilon}^2 = \bar{x}^2 + (\hat{\epsilon})^2 \]

\[ \hat{\epsilon} = \frac{\hat{\epsilon}}{\epsilon} \sqrt{\frac{1}{\epsilon^2} + (\hat{\epsilon})^2} = \frac{1 \times 10^{-4}}{3.9 \times 10^{-4}} \cdot 0.1 = 0.026 \text{ m} \]

26 mm is much, much bigger than the undulator amplitude (~ 0.04 mm), so emittance growth in negligible.
Transverse Momentum Due to Laser

\[
\begin{align*}
\Delta p_{x,B} &= \frac{e\hat{E} L}{c} \int_{0}^{L/L_c} \frac{K^2}{4L_c^2} \cos 2k_0 s \cos (1 - b)ks + \frac{bK^2k}{16L_c^2} \sin (2k_0 s) ds \\
\Delta p_{x,E} &= \frac{e\hat{E}}{c} \cos (1 - b) ks + \frac{bK^2k}{16L_c^2} \sin 2k_0 s ds
\end{align*}
\]

Beam angular spread is 50 \( \mu \text{rad} \). Maximum laser induced transverse angle is 0.1 \( \mu \text{rad} \), so it can be ignored.
Laser/Electron Beam Angle

Good Polarization -
E is only in x direction

Bad Polarization -
E has component in z direction

0.001 mrad angle, 10% loss of modulation