LCLS-II HXU Measurement Results

Serial number from manufacturers label: | HXU-011

Measurement Procedure:
The measurements have been carried out after the undulator segment had been fully tuned according to the “LCLS-II Undulator Test Plan” (LCLS-TN-17-1).

General Hall Probe Scan Evaluation Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Undulator Temperature (should be 20.0)</td>
<td>20.0 ± 0.1 °C</td>
</tr>
<tr>
<td>First core pole #</td>
<td>8</td>
</tr>
<tr>
<td>Last core pole #</td>
<td>253</td>
</tr>
<tr>
<td>Tuning Gap</td>
<td>9.000 mm</td>
</tr>
</tbody>
</table>

Evaluation of Hall Probe Scans at Commissioning Gap

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commissioning Gap Temperature (should be 20.0)</td>
<td>20.0 ± 0.1 °C</td>
</tr>
<tr>
<td>$\text{rms} (</td>
<td>B_{pk}</td>
</tr>
<tr>
<td>$K_{\text{eff}}$ at Commissioning Gap (should be 2.3400)</td>
<td>2.3402</td>
</tr>
<tr>
<td>Commissioning Gap</td>
<td>7.934 mm</td>
</tr>
<tr>
<td>$I_1 X$ (over 4.012667 m) (should be within ±40)</td>
<td>-6 $\mu$TM</td>
</tr>
<tr>
<td>$I_2 X$ (over 4.012667 m) (should be within ±150)</td>
<td>0 $\mu$TM</td>
</tr>
<tr>
<td>$I_1 Y$ (over 4.012667 m) (should be within ±40)</td>
<td>-5 $\mu$TM</td>
</tr>
<tr>
<td>$I_2 Y$ (over 4.012667 m) (should be within ±150)</td>
<td>7 $\mu$TM</td>
</tr>
<tr>
<td>Phase Shake (rms phase fluctuations over core poles (&lt; 4.0))</td>
<td>1.3 degXray</td>
</tr>
<tr>
<td>Cell Phase Advance (over 4.012667 m)</td>
<td>48598.6 (135×360−1.4) degXray</td>
</tr>
<tr>
<td>Undulator Entrance Phase$^1$</td>
<td>2249.0 (25×90−1.0) degXray</td>
</tr>
<tr>
<td>Undulator Exit Phase$^2$</td>
<td>2248.0 (25×90−2.0) degXray</td>
</tr>
</tbody>
</table>

$^1$Phase advance from cell start (undulator center −2.006334 m) to center of physical pole 8.

$^2$Phase advance from physical pole 253 to cell end (undulator center +2.006334 m).
### Undulator Encoder Settings

<table>
<thead>
<tr>
<th>Encoder Type</th>
<th>Offset Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>USGapEncoderOffset</td>
<td>40.3898</td>
</tr>
<tr>
<td>DSGapEncoderOffset</td>
<td>40.0815</td>
</tr>
<tr>
<td>USWLinearEncoder.AOFF</td>
<td>92.0303</td>
</tr>
<tr>
<td>DSWLinearEncoder.AOFF</td>
<td>94.0350</td>
</tr>
<tr>
<td>USALinearEncoder.AOFF</td>
<td>92.8664</td>
</tr>
<tr>
<td>DSALinearEncoder.AOFF</td>
<td>92.2437</td>
</tr>
</tbody>
</table>

### Undulator Load Cell Readings at Tuning Gap (Gap Opening)

<table>
<thead>
<tr>
<th>Load Cell Type</th>
<th>Force Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>LC.DAL_FORCE</td>
<td>-252.0</td>
</tr>
<tr>
<td>LC.DAU_FORCE</td>
<td>-194.8</td>
</tr>
<tr>
<td>LC.DWL_FORCE</td>
<td>-185.5</td>
</tr>
<tr>
<td>LC.DWU_FORCE</td>
<td>-190.9</td>
</tr>
<tr>
<td>LC.UAL_FORCE</td>
<td>-232.2</td>
</tr>
<tr>
<td>LC.UAU_FORCE</td>
<td>-170.7</td>
</tr>
<tr>
<td>LC.UWL_FORCE</td>
<td>-225.1</td>
</tr>
<tr>
<td>LC.UWU_FORCE</td>
<td>-196.5</td>
</tr>
</tbody>
</table>

### Undulator Load Cell Readings at 100 mm Gap (Gap Opening)

<table>
<thead>
<tr>
<th>Load Cell Type</th>
<th>Force Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>LC.DAL_FORCE</td>
<td>0.7</td>
</tr>
<tr>
<td>LC.DAU_FORCE</td>
<td>3.2</td>
</tr>
<tr>
<td>LC.DWL_FORCE</td>
<td>7.1</td>
</tr>
<tr>
<td>LC.DWU_FORCE</td>
<td>4.4</td>
</tr>
<tr>
<td>LC.UAL_FORCE</td>
<td>5.6</td>
</tr>
<tr>
<td>LC.UAL_FORCE</td>
<td>3.4</td>
</tr>
<tr>
<td>LC.UWL_FORCE</td>
<td>4.2</td>
</tr>
<tr>
<td>LC.UWU_FORCE</td>
<td>-0.2</td>
</tr>
</tbody>
</table>
Evaluation of Hall Probe Scans: $K_{\text{eff}}$ vs. gap
Evaluation of Hall Probe Scans: \( K_{\text{eff}} \) Hysteresis using Half Gap Encoders

Plotted functions have been calculated from measured values open\( K_{\text{eff}} \) (opengap) and close\( K_{\text{eff}} \) (closegap) using the following Matlab calculations:

Blue Stars: \( 1 \cdot \text{open}\_K_{\text{eff}} ./ \text{spline} (\text{opengap}([1,2,[3:2:end]]),\text{open}\_K_{\text{eff}}([1,2,[3:2:end]]),\text{opengap}) \)

Green Stars: \( 1 \cdot \text{close}\_K_{\text{eff}} ./ \text{spline} (\text{opengap}([1,2,[3:2:end]]),\text{close}\_K_{\text{eff}}([1,2,[3:2:end]]),\text{closegap}) \)
Evaluation of Hall Probe Scans: $K_{\text{eff}}$ Hysteresis using Full Gap Encoders

Plotted functions have been calculated from measured values $\text{openKeff}$ (opengap) and $\text{closeKeff}$ (closegap) using the following Matlab calculations:

Blue Stars: $1 - \text{openKeff} ./ \text{spline(opengap([1,2,[3:2:end]]),openKeff([1,2,[3:2:end]]),opengap)}$

Green Stars: $1 - \text{closeKeff} ./ \text{spline(opengap([1,2,[3:2:end]]),openKeff([1,2,[3:2:end]]),closegap)}$

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Evaluation of Hall Probe Scans: Phase Shake vs gap
Evaluation of Hall Probe Scans: $K_{\text{eff}}$ vs $x$ at Tuning Gap

HXU-011: $K_{\text{eff}}$ vs. $x$ @ Tuning Gap

Tuning Gap = 9.0 mm

$K_{\text{eff}}(x) = 0.0589/\text{mm}^2 x^2 + 0.0010/\text{mm} x + 2.0051$

$x_{\text{center}} = 0.008$ mm
Evaluation of Hall Probe Scans: $K_{\text{eff}}$ vs $Y$ at Tuning Gap

**HXU-011: $K_{\text{eff}}$ vs. $y$ @ Tuning Gap**

Tuning Gap = 9.0mm

$K_{\text{eff}}(y) = 0.000167/\text{mm} \times x + 2.0051$
Long Coil Measurement of the On-Axis First Horizontal Field Integrals with +100 $\mu$T·m Integral Offset

![Graph showing HXU-011: I1x vs. gap (Integral Correction Offset Applied)](image)

- First Field Integral x
- Tolerance (+40 $\mu$T·m)
- Tolerance (-40 $\mu$T·m)
Long Coil Measurement of the On-Axis First Horizontal Field Integrals

HXU-011: I1x vs. gap (Direct Measurement)
Long Coil Measurement of the On-Axis Second Horizontal Field Integrals with $+100 \, \mu T \cdot m \times 0.5 \times 4.012667 \, m$ Second Integral Offset

**HXU-011: I2x vs. gap (Integral Correction Offset Applied)**

- Second Field Integral $x \ [\mu T \cdot m^2]$
- Tolerance ($+150 \, \mu T \cdot m^2$)
- Tolerance ($-150 \, \mu T \cdot m^2$)

**Graph Details:**
- X-axis: Full Gap [mm]
- Y-axis: Second Field Integral $x \ [\mu T \cdot m^2]$
- Data points represent the measured values of the second integral offset applied.
Long Coil Measurement of the On-Axis Second Horizontal Field Integrals

**HXU-011: I2x vs. gap (Direct Measurement)**

![Graph showing the relationship between Full Gap (mm) and Second Field Integral (μT·m²)]
Long Coil Measurement of the On-Axis First Vertical Field Integrals

**HXU-011: I₁y vs. gap**

- First Field Integral y
- Tolerance (+40 μT·m)
- Tolerance (-40 μT·m)
Long Coil Measurement of the On-Axis Second Vertical Field Integrals

**HXU-011: \( I_2y \) vs. gap**

![Graph showing \( I_2y \) vs. gap](image URL)

- Second Field Integral \( y \) \([\mu T \cdot m^2]\)
- Tolerance (+150 \( \mu T \cdot m^2 \))
- Tolerance (-150 \( \mu T \cdot m^2 \))
Second Horizontal and Vertical Field Integrals Along Undulator Length at Commissioning Gap

![Graph showing second field integral vs. z (commissioning gap) for HXU-011]
The following plots show the pole and magnet position measurements. The LBNL system has two back-to-back capacitive probes on one probe holder. The x and y stages on the Kugler bench are positioned so that the probe is in the proper location for each of the 9 scan locations. For the data analysis, the average pole position in each scan is used as reference for the plotted pole and magnet positions. Note that for all plots, the first three and last three poles of the device are omitted since the measurement is not accurate due to end effects in the capacitance probe measurement.
G1 Capacitive Sensor Readings

HXU-011: Distance from Probe (Aisle Top)

Distance [mm]

z [m]

-0.05 0 0.05 0.1 0.15 0.2 0.25

Poles
Magnets

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G2 Capacitive Sensor Readings

![Graph showing the distance from the probe to the aisle bottom with two distinct markers for poles and magnets.](image)
G3 Capacitive Sensor Readings
G4 Capacitive Sensor Readings

**HXU-011: Distance from Probe (Wall Bottom)**

- **Distance [mm]**
- **z [m]**

Graph showing the distance from the probe to the wall bottom with two traces: one for poles and another for magnets.
Undulator Gap Measurement

HXU-011: Undulator Gap Measurement

- Gap = 30.0 mm
- Gap = 7.2 mm

Graph showing gap deviation in micrometers (μm) versus axial position (z [m]).
**LCLS-II Undulator Segment Measurement Results**

**HXU-011**

**Undulator Gap Difference**

HXU-011: Gap Shape Change [gap(7.2) minus gap(30)]

**Graph**

- **Gap Distortion**
- **Tolerance: +9.5 μm**
- **Tolerance: -9.5 μm**

**Axes**
- **z [m]**
- **Gap Distortion [μm]**
- **Range:**
  - -10 to 10
  - -2 to 2
Drive Loads (Gap Opening)

HXU-011 Drive Load Forces

![Graph showing drive loads vs full gap](image)

- Drive Load Force [N]
- Full Gap [mm]
- HXU-011 Drive Load Forces

Legend:
- $F_{\text{Aisle}}^{\text{up}}$ opening
- $F_{\text{Wall}}^{\text{up}}$ opening
- $F_{\text{Aisle}}^{\text{dn}}$ opening
- $F_{\text{Wall}}^{\text{dn}}$ opening
- Tolerance (+0 N)
- Tolerance (-700 N)
Drive Load Differences (Gap Opening and Closing)

HXU-011 Drive Load Differences: Upstream - Downstream

Graph showing the drive load force difference in N for different gap opening and closing conditions. The graph includes lines for aisle closing, wall closing, aisle opening, and wall opening, along with tolerance lines at ±130 N.
Strongback Forces (Gap Opening and Closing)

HXU-011 Strongback Forces

![Graph showing strongback forces vs. gap opening and closing](image)

- **F_{aisle}** closing
- **F_{aisle}** opening
- **F_{wall}** closing
- **F_{wall}** opening

Tolerance (+0 N)
Tolerance (-1400 N)
HXU-011 Strongback Force Differences: Aisle - Wall

- $F_{\text{Aisle}} - F_{\text{Wall}}$ (closing)
- $F_{\text{Aisle}} - F_{\text{Wall}}$ (opening)

Tolerance (+200 N) and (-200 N)