LCLS-II HXU Measurement Results

Serial number from manufacturers label: HXU-026

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>( r_m s (|B_{pk}|/\langle</td>
<td>B_{pk}</td>
</tr>
<tr>
<td>( K_{eff} ) at Commissioning Gap (should be 2.3400)</td>
<td>2.3399</td>
</tr>
<tr>
<td>Commissioning Gap</td>
<td>7.961 mm</td>
</tr>
<tr>
<td>( I_{1X} ) (over 4.012667 m) (should be within ±40)</td>
<td>0 ( \mu Tm )</td>
</tr>
<tr>
<td>( I_{2X} ) (over 4.012667 m) (should be within ±150)</td>
<td>7 ( \mu Tm^2 )</td>
</tr>
<tr>
<td>( I_{1Y} ) (over 4.012667 m) (should be within ±40)</td>
<td>-1 ( \mu Tm )</td>
</tr>
<tr>
<td>( I_{2Y} ) (over 4.012667 m) (should be within ±150)</td>
<td>6 ( \mu Tm^2 )</td>
</tr>
<tr>
<td>Phase Shake (rms phase fluctuations over core poles (&lt; 4.0))</td>
<td>1.4 degXray</td>
</tr>
<tr>
<td>Cell Phase Advance (over 4.012667 m)</td>
<td>48600.2 (135×360+0.2) degXray</td>
</tr>
<tr>
<td>Undulator Entrance Phase(^1)</td>
<td>2250.3 (25×90+0.3) degXray</td>
</tr>
<tr>
<td>Undulator Exit Phase(^2)</td>
<td>2247.5 (25×90−2.5) 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 Offset</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>USGapEncoderOffset</td>
<td>40.6724</td>
</tr>
<tr>
<td>DSGapEncoderOffset</td>
<td>40.3684</td>
</tr>
<tr>
<td>USWLinearEncoder.AOFF</td>
<td>92.2298</td>
</tr>
<tr>
<td>DSWLinearEncoder.AOFF</td>
<td>92.0298</td>
</tr>
<tr>
<td>USALinearEncoder.AOFF</td>
<td>91.8239</td>
</tr>
<tr>
<td>DSALinearEncoder.AOFF</td>
<td>93.3913</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Load Cell Force</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>LC_DAL_FORCE</td>
<td>-193.8</td>
</tr>
<tr>
<td>LC_DAU_FORCE</td>
<td>-295.9</td>
</tr>
<tr>
<td>LC_DWL_FORCE</td>
<td>-217.5</td>
</tr>
<tr>
<td>LC_DWU_FORCE</td>
<td>-305.7</td>
</tr>
<tr>
<td>LC_UAL_FORCE</td>
<td>-199.7</td>
</tr>
<tr>
<td>LC_UAU_FORCE</td>
<td>-264.6</td>
</tr>
<tr>
<td>LC_UWL_FORCE</td>
<td>-282.7</td>
</tr>
<tr>
<td>LC_UWU_FORCE</td>
<td>-140.9</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Load Cell Force</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>LC_DAL_FORCE</td>
<td>2.9</td>
</tr>
<tr>
<td>LC_DAU_FORCE</td>
<td>-0.5</td>
</tr>
<tr>
<td>LC_DWL_FORCE</td>
<td>1.5</td>
</tr>
<tr>
<td>LC_DWU_FORCE</td>
<td>0.5</td>
</tr>
<tr>
<td>LC_UAL_FORCE</td>
<td>6.6</td>
</tr>
<tr>
<td>LC_UAL_FORCE</td>
<td>1.2</td>
</tr>
<tr>
<td>LC_UWL_FORCE</td>
<td>10.3</td>
</tr>
<tr>
<td>LC_UWU_FORCE</td>
<td>9.8</td>
</tr>
</tbody>
</table>
Evaluation of Hall Probe Scans: $K_{\text{eff}}$ vs. gap

![Graph showing $K_{\text{eff}}$ vs. gap](image-url)
Evaluation of Hall Probe Scans: $K_{\text{eff}}$ Hysteresis using Half Gap Encoders

Plotting 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:** 
$$1 - \frac{\text{open}K_{\text{eff}}}{\text{spline(opengap([1,2,[3:2:end]]),openKeff([1,2,[3:2:end]]),opengap)}}$$

**Green Stars:** 
$$1 - \frac{\text{close}K_{\text{eff}}}{\text{spline(opengap([1,2,[3:2:end]]),openKeff([1,2,[3:2:end]]),closegap)}}$$

Tolerance (+0.00023) and Tolerance (-0.00023) are displayed on the graph.
HXU-026: $K_{\text{eff}}$ Hysterisis and Spline Fit QA

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-$\text{closeKeff} ./ \text{spline(opengap([1,2,[3:2:end]]),openKeff([1,2,[3:2:end]]),closegap})$
Evaluation of Hall Probe Scans: Phase Shake vs gap

![Graph showing phase shake vs. gap]

- **HXU-026**: phase shake vs. gap
-轴: Full Gap [mm]
-轴: phase shake [degXray]
Evaluation of Hall Probe Scans: $K_{\text{eff}}$ vs $x$ at Tuning Gap

$$K_{\text{eff}}(x) = 0.0592/mm^2 x^2 + 0.0007/mm x + 2.0090$$

$x_{\text{center}} = 0.006$ mm
Evaluation of Hall Probe Scans: $K_{\text{eff}}$ vs Y at Tuning Gap

**HXU-026: $K_{\text{eff}}$ vs. y @ Tuning Gap**

Tuning Gap = 9.0mm

$K_{\text{eff}}(y) = 0.000000/\text{mm} \times + 2.0089$
Long Coil Measurement of the On-Axis First Horizontal Field Integrals with +100 \( \mu \)T·m Integral Offset

![Graph](image)

**Graph Title:** HXU-026: I1x vs. gap (Integral Correction Offset Applied)

**Legend:**
- 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

![Graph showing the relationship between First Field Integral and Full Gap (Direct Measurement)](image)

**HXU-026: I1x vs. gap (Direct Measurement)**

- **X-axis:** Full Gap [mm]
- **Y-axis:** First Field Integral: x [μT.m]
Long Coil Measurement of the On-Axis Second Horizontal Field Integrals with $+100 \, \mu \text{T} \cdot \text{m} \times 0.5 \times 4.012667 \, \text{m}$ Second Integral Offset

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**HXU-026: $I_2x$ vs. gap (Integral Correction Offset Applied)**

[Graph showing $I_2x$ vs. gap with integral correction offset applied]
Long Coil Measurement of the On-Axis Second Horizontal Field Integrals

**HXU-026: I(x) vs. gap (Direct Measurement)**

![Graph showing the relationship between second field integral and gap](image)

- The graph represents the second field integral, $I(x)$, as a function of the gap in millimeters.
- The data is plotted directly from measurements.

**Key Points**
- The second field integral decreases as the gap increases.
- The relationship is linear within the measured range.

**Legend**
- $I(x)$: Second Field Integral, units: $\mu T \cdot m^2$.
Long Coil Measurement of the On-Axis First Vertical Field Integrals

HXU-026: $I_{1y}$ vs. gap

- First Field Integral $y$ ($\mu T\cdot m$)
- Tolerance (+40 $\mu T\cdot m$)
- Tolerance (-40 $\mu T\cdot m$)
Long Coil Measurement of the On-Axis Second Vertical Field Integrals

HXU-026: I2y vs. gap

- Second Field Integral y
- Tolerance (+150 μT.m²)
- Tolerance (-150 μT.m²)
Second Horizontal and Vertical Field Integrals Along Undulator Length at Commissioning Gap

![Graph showing second field integral vs. z (Commissioning Gap)](image)
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
G2 Capacitive Sensor Readings

![Graph showing distance from probe (Aisle Bottom) for HXU-026](image)

**HXU-026: Distance from Probe (Aisle Bottom)**

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

- **Poles**
- **Magnets**
G3 Capacitive Sensor Readings

HXU-026: Distance from Probe (Wall Top)

Distance [mm]  

-0.05  0  0.05  0.1  0.15  0.2  0.25

z [m]  

-2 -1.5 -1 -0.5 0 0.5 1 1.5 2

Poles
Magnets
G4 Capacitive Sensor Readings

HXU-026: Distance from Probe (Wall Bottom)

- Distance [mm]
- z [m]

-2 -1.5 -1 -0.5 0 0.5 1 1.5 2

-0.05 0 0.05 0.1 0.15 0.2 0.25

Poles
Magnets
Undulator Gap Measurement

HXU-026: Undulator Gap Measurement

- Gap = 30.0 mm
- Gap = 7.2 mm

Graph showing gap deviation over z [m] with markers for two gap sizes.
Undulator Gap Difference

HXU-026: Gap Shape Change [gap(7.2) minus gap(30)]

- Gap Distortion
- Tolerance: +9.5 μm
- Tolerance: -9.5 μm
Drive Loads (Gap Opening)

![Graph showing drive load forces for HXU-026](Image)

- Drive Load Force [N]
- Full Gap [mm]
- Tolerance (+0 N)
- Tolerance (-700 N)
Drive Load Differences (Gap Opening and Closing)

HXU-026 Drive Load Differences: Upstream - Downstream

- Drive Load Force Difference [N]
- Full Gap [mm]
- ΔFAisle closing
- ΔFWall closing
- ΔFAisle opening
- ΔFWall opening
- Tolerance (+130 N)
- Tolerance (-130 N)
Strongback Forces (Gap Opening and Closing)

**HXU-026 Strongback Forces**

![Graph showing HXU-026 Strongback Forces](image)

- **F<sub>Aisle</sub> closing**
- **F<sub>Wall</sub> closing**
- **F<sub>Aisle</sub> opening**
- **F<sub>Wall</sub> opening**

**Tolerance**
- (+0 N)
- (-1400 N)
LCLS-II Undulator Segment Measurement Results

Strongback Force Differences (Gap Opening and Closing)

HXU-026

HXU-026 Strongback Force Differences: Aisle - Wall

-200
-100
0
100
200
Strongback Force Difference [N]

Full Gap [mm]

F_{Aisle} - F_{Wall} closing
F_{Aisle} - F_{Wall} opening
Tolerance (+200 N)
Tolerance (-200 N)