Performance of Small-Gap Undulators at the SLS Intermediate Energy Storage Ring

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In Vacuum Undulators

Performance of Small-Gap Undulators at the SLS Intermediate Energy Storage Ring


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Abstract. The Swiss Light Source (SLS) at the Paul Scherrer Institut (PSI) became the first medium energy synchrotron user facility to rely on the high harmonic operation of small gap, short period undulators to extend high brightness radiation into a regime (3-18 keV) otherwise only accessible using lower brightness wigglers or operation at higher electron beam energy. Today several facilities with beam energy 2-3 GeV follow a similar route. A PSI/SPRing-8 collaboration was formed to install and operate the first in-vacuum undulator shortly after commissioning of the SLS storage ring (2.4 GeV) in 2001. The goal of the joint project was to prove that high harmonic operation of small period undulators at small gaps is a valid concept to operate the PX-I beamline at 1 Å under user operation conditions. The performance of the PX-I beamline proved to be excellent and launched the installation of 4 new in-vacuum undulators. Having routinely operated such devices for 5 years, our experience confirms that (1) the concept of operating short period undulators (19-24 mm) on higher harmonics (11/13) is valid, (2) a reliable small gap (5-6 mm) undulator operation is feasible in the presence of top-up injection, and (3) during gap scans the photon beam can be stabilized to sub-μrad precission using non-intercepting photon beam monitors.

Keywords: short period undulator, high harmonic operation, x-ray beam stability.
PACS: 41.85.Lc, 41.60.Ap, 42.65.Ky

( G. Ingold et al., SRI 2006, Korea, May 28 - June 2, 2006. )
In Vacuum Undulators

First In Vacuum Undulator Installed at SLS: U24 (in 2001)

PSI/SPring-8 Collaboration
U24 Undulator: Magnetic Performance

- Measurement: 1st field integrals (flip coil), 2nd field integrals (hall probe)
- Phase error: $< 2.5^0$
- Optimization: magnet module swapping (T. Tanaka et al., NIM 465 (2001) 600.)
- New U19 undulator: specification according to U24 performance
- Decision: new undulators are ordered at companies who are responsible for magnetic measurements and optimization according to SLS specifications
### Magnetic Specifications

<table>
<thead>
<tr>
<th>Specifications:</th>
<th>Multipoles:</th>
<th>50 G</th>
<th>Quadrupole (norm &amp; skew)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>60 G/cm</td>
<td>Sextupole</td>
<td></td>
</tr>
<tr>
<td></td>
<td>100 G/cm²</td>
<td>Octupole</td>
<td></td>
</tr>
</tbody>
</table>

Accepted field integral variation

- +/- 20 Gcm within +/- 10 mm
- +/- 50 Gcm within +/- 20 mm

Phase error: < 2.5 degree rms

Taper: < 5 μm

**Status:**

- 4 U19 in-vac undulators installed
- Gap range: 5 (4.5) – 8.5 (12) mm (3 -20 keV)
- 12 keV: 9\(^{th}\) harmonic, 17 keV: 13\(^{th}\) harmonic

All undulators within specs (i.e. phase errors < 2.5 degree

**exception:** SLS 5L (3.5 degree for 6 – 8 mm)

- 20% (40%) reduction for 12 (17) keV

- **Experience:** 4 in-vacuum undulators (and 5 polarized undulators) are operated during top-up operation. There is no indication any ID is limiting the dynamic aperture.
New: Short Period, Small Gap Undulator U19

Measured flux at 2.4 GeV & 8 keV: $8 \times 10^{12}$ ph/s/400 mA/0.01% bw (gap: 6 mm)

[Installed at 4 beamlines: μXAS/FEMTO, PX-I, PX-II, cSAXS]
The SLS became the first medium energy user facility to rely on the high harmonic operation of small gap, short period undulators to reach $\sim 18$ keV

Independent of the vendor (Sumitomo/Neomax $\oplus$ Danfysik) all devices are high performing undulators according to SLS specifications
Small Gap Operation ↔ Risk of Radiation Damage

- U24 measured spectrum (7th harmonic): no indication of radiation damage
- No change in spectral performance: 3.5 years of operation (ca. 2.5 years in top-up mode)
- Magnet: NEOMAX-32EH (not the most resistive material, see Bizen et al., SPring-8)
## Magnet Materials

<table>
<thead>
<tr>
<th></th>
<th>Sumitomo I</th>
<th>Sumitomo II</th>
<th>Danfysik</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Magnets</strong></td>
<td>NdFeB</td>
<td>NdFeB</td>
<td>Sm$<em>2$Co$</em>{17}$</td>
</tr>
<tr>
<td><strong>Poles</strong></td>
<td>Permendur</td>
<td>Permendur</td>
<td>Armco</td>
</tr>
<tr>
<td>Br reached</td>
<td>1.11 – 1.19 T</td>
<td>1.02 – 1.1 T</td>
<td>1.05 T</td>
</tr>
<tr>
<td>1.158 T</td>
<td>1.095 T</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hcj</td>
<td>&gt; 30 kOe</td>
<td>&gt; 36 kOe</td>
<td>25 kOe</td>
</tr>
<tr>
<td>nom/min gap</td>
<td>5/5.5mm</td>
<td>5/4.5 mm</td>
<td>5/4.5 mm</td>
</tr>
<tr>
<td>Beff</td>
<td>0.939 T</td>
<td>0.871 T</td>
<td>0.86 T</td>
</tr>
<tr>
<td>Keff</td>
<td>1.67</td>
<td>1.55</td>
<td>1.53</td>
</tr>
</tbody>
</table>

- 3 different magnet materials used: check possible radiation damage by spectral performance
In Vacuum Undulators

Impact on e-beam orbit & XBPM-calibration

- (a) FF and FOFB corrections switched off: change of local BPM readings with gap
- (b) XBPM calibration: linear dependence on parallel e-beam displacement in the undulator
In Vacuum Undulators

X-Ray Beam Pointing Stability $\leq 1 \mu$rad

ID feedforward (ID-FF) scheme using X-ray beam position monitors (XBPMs).

FOFB and ID-FF corrections: residual motion $1 \mu$m (8.6 m distance from source point).

In Vacuum Undulators

Undulator Construction: Vendor & PSI

- Vendor (NEOMAX + DANFYSIK): mechanics, magnetics (+ mag. measurements), vacuum
- PSI: vacuum (taper transitions), electrics, control, alignment (mover), diagnostic+interlock
Undulator Magnetic Measurements: Stretched & Pulsed Wire

- Magnetic measurements after delivery: 1st & 2nd integral (stretched wire) and trajectory straightness (pulsed wire)
U19 In-Vac Undulator: Installion at the SLS Storage Ring

- In-situ alignment (≤50 μm): undulator installed on mover system
- Gap-reading: linear encoders (shielded) attached to the outer backing beam
U19 Undulators: Mechanical Precision - Gap Taper

• All undulators driven with 1 motor
• Hysteresis and strong variation in tuning range at specs limit
• with 2 motor option: zero taper

- Measurement of mechanical gap taper (linear vs. rotary encoder), specified: \( \leq 5 \, \mu m \)
- Achieved (for 3 IDs) with 1-motor operation (optional: 2-motor operation for taper \( \sim 1 \, \mu m \))
• Failure concerning in-vac undulator operation at SLS in 5 years: 2 water failures
• Critical: pipes for internal water-cooling; flexible taper (leak developed, reason unknown)
In-vacuum undulators are a proven technology

- High harmonic operation at intermediate energy storage rings is a valid concept
- No radiation damage has been observed (under conditions of top-up operation)
- High performance (hybrid) in-vac undulators are commercially available
- Next step at SLS: cryogenic in-vac undulator to replace high field, short period wiggler