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

Gerhard Ingold

Paul Scherrer Institut

Laboratory for Synchrotron Radiation

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In Vacuum Undulators at SLS

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

G. Ingold, M. Boege, W. Bulgheroni, A. Keller, J. Krempaski, C. Schulze-Briese, L. Schulz, T. Schmidt, D. Zimoch* and T. Hara, T. Tanaka, H. Kitamura†

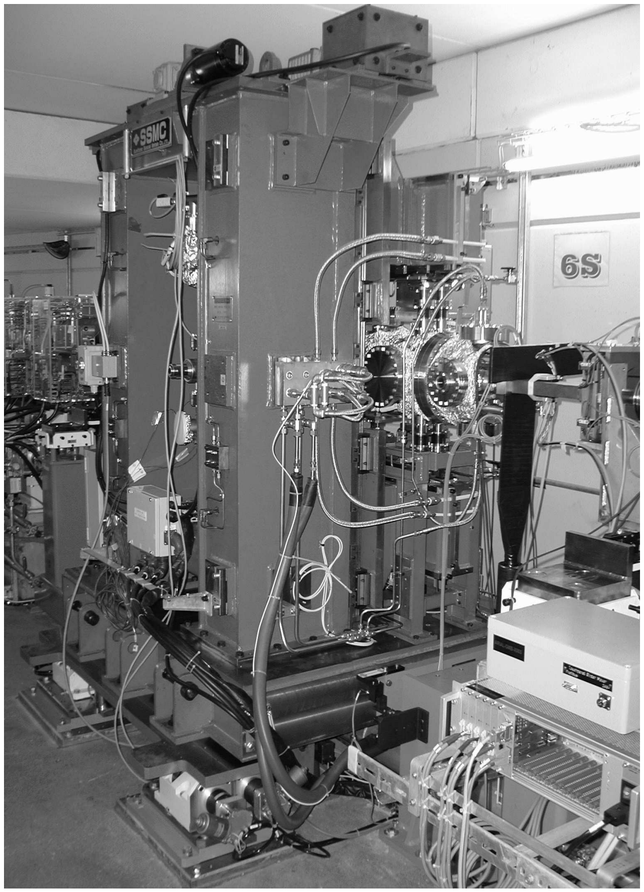
**Swiss Light Source, Paul Scherrer Institute, CH-5232 Villigen, Switzerland*
†RIKEN/SPring-8, 1-1-1 Koutu, Mikazuki-cho, Sayo-gun, Hyogo 679-5148, Japan

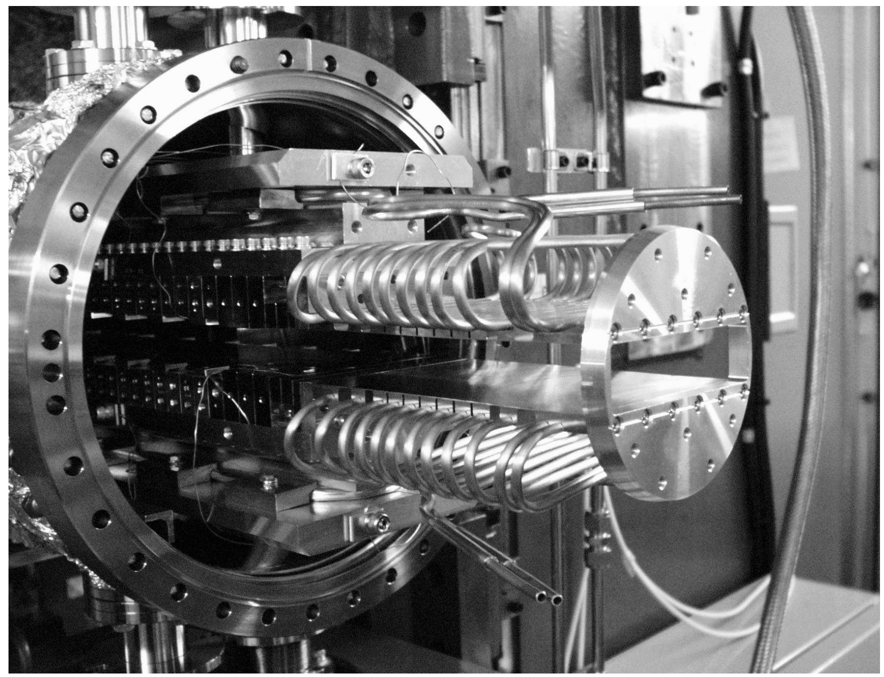
Abstract. The Swiss Light Source (SLS) at the Paul Scherrer Institut (PSI) became the first medium energy synchrotron user facility to rely on the high harmonic operation of small gap, short period undulators to extend high brightness radiation into a regime (3-18 keV) otherwise only accessible using 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 precesion 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.)

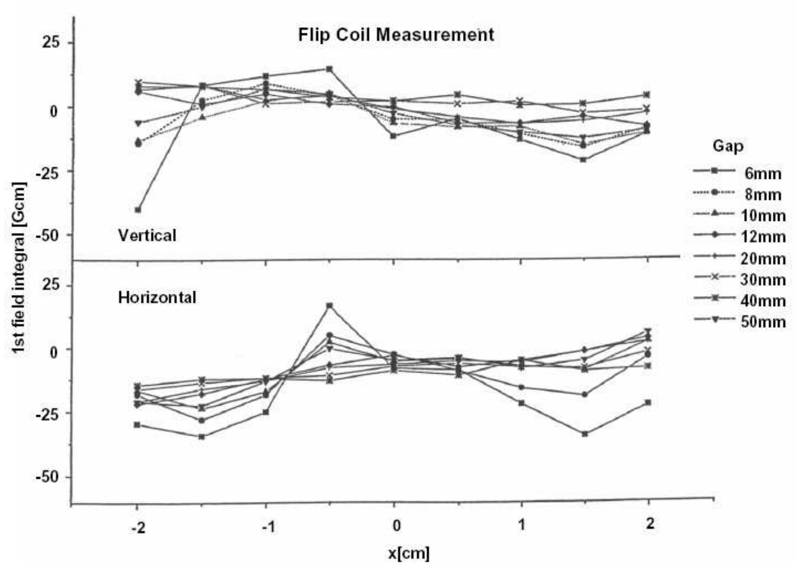
First In Vacuum Undulator Installed at SLS: U24 (in 2001)

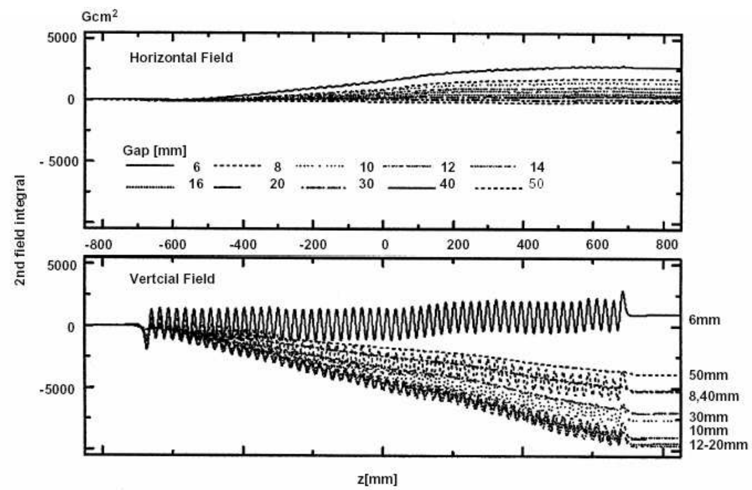




PSI/SPring-8 Collaboration

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 Specifi cations

Specifications:	Multipoles:	50 G	Quadrupole (norm & skew)
		60 G/cm	Sextupole
		100 G/cm2	Octupole
	Accepted field integral variation		
		+- 20 Gcm	within +- 10 mm
		+- 50 Gcm	within +- 20 mm
	Phase error	< 2.5 degree rms	
	Taper	< 5 µm	

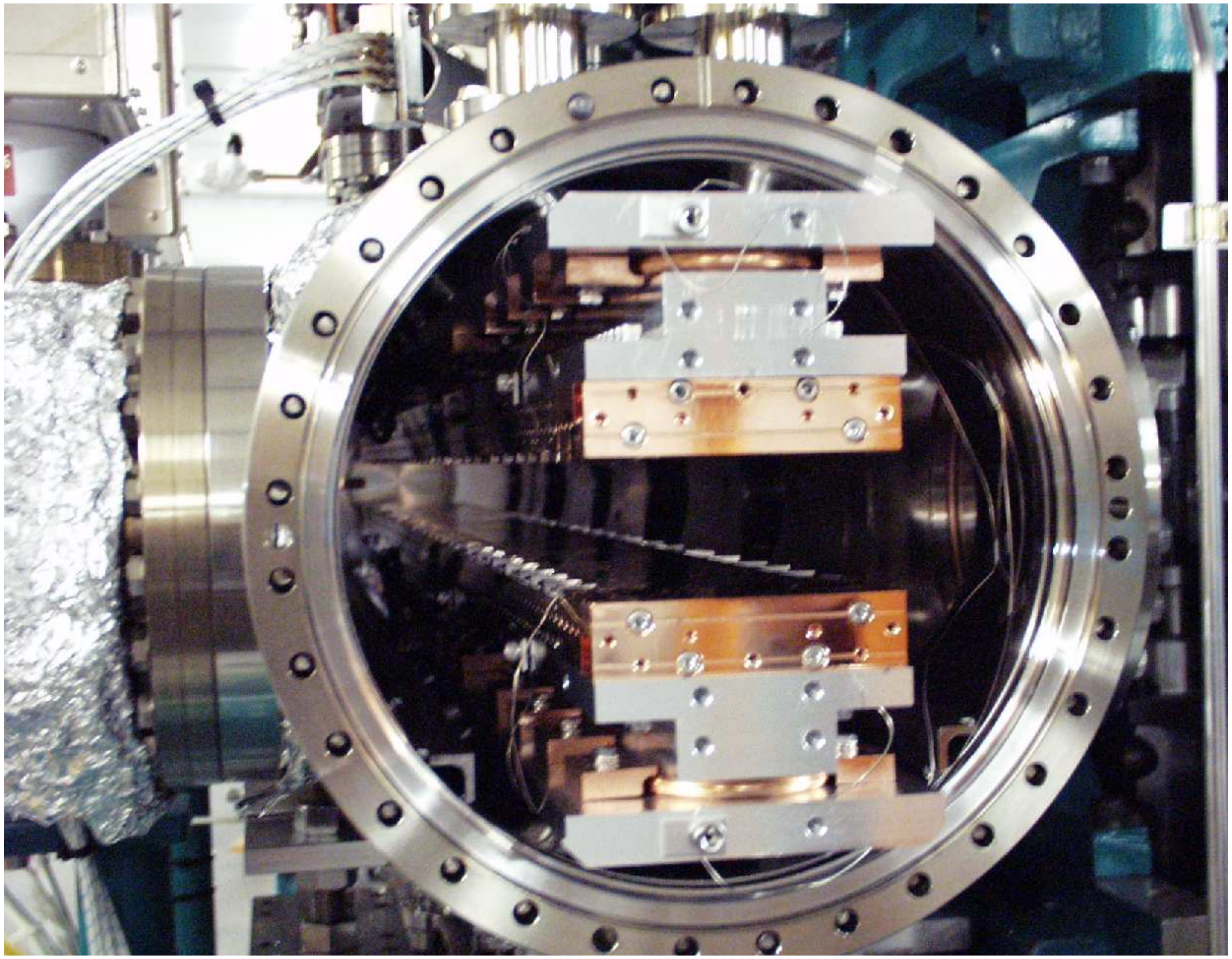
Status:

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

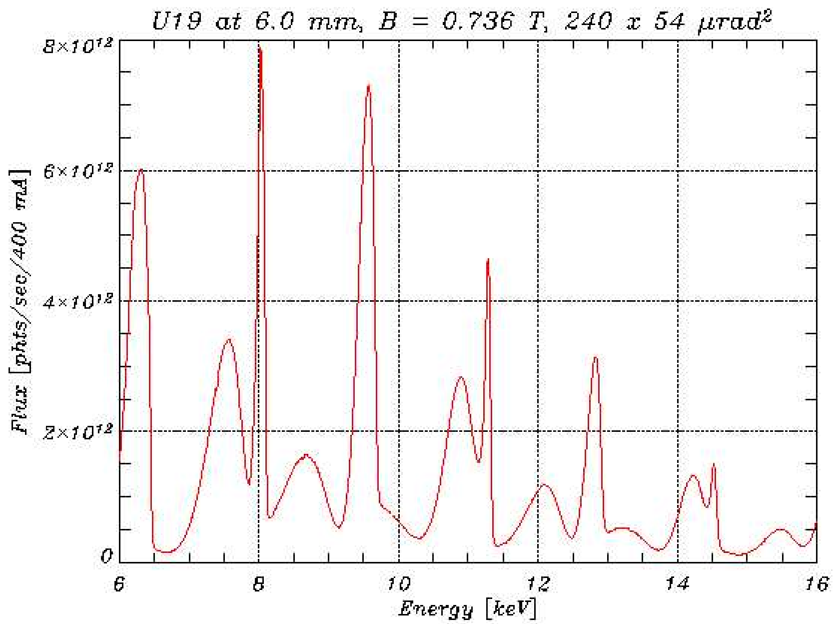
New: Short Period, Small Gap Undulator U19

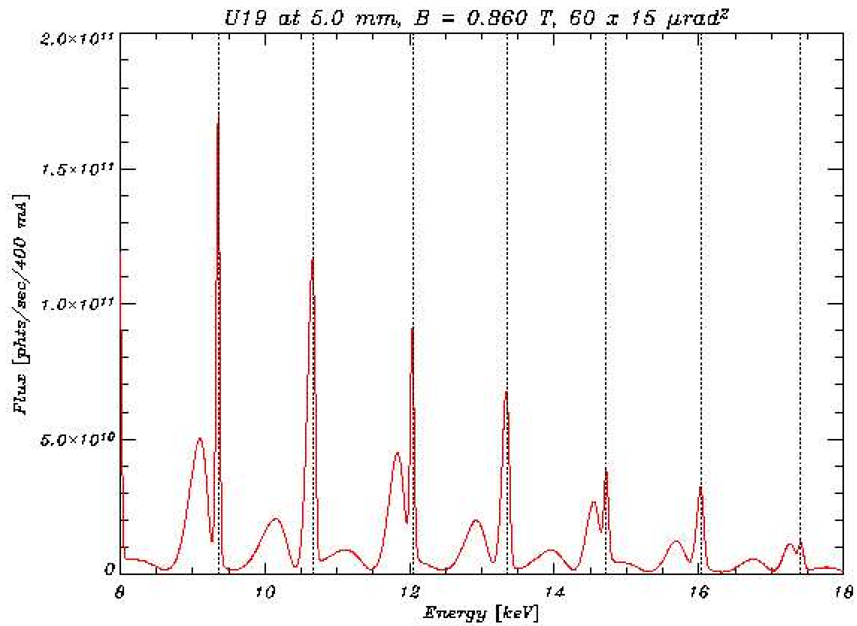


Measured flux at 2.4 GeV & 8 keV: $8{\cdot}10^{12}$ ph/s/400 mA/0.01% bw (gap: 6 mm)

[Installed at 4 beamlines: μXAS/FEMTO, PX-I, PX-II, cSAXS]

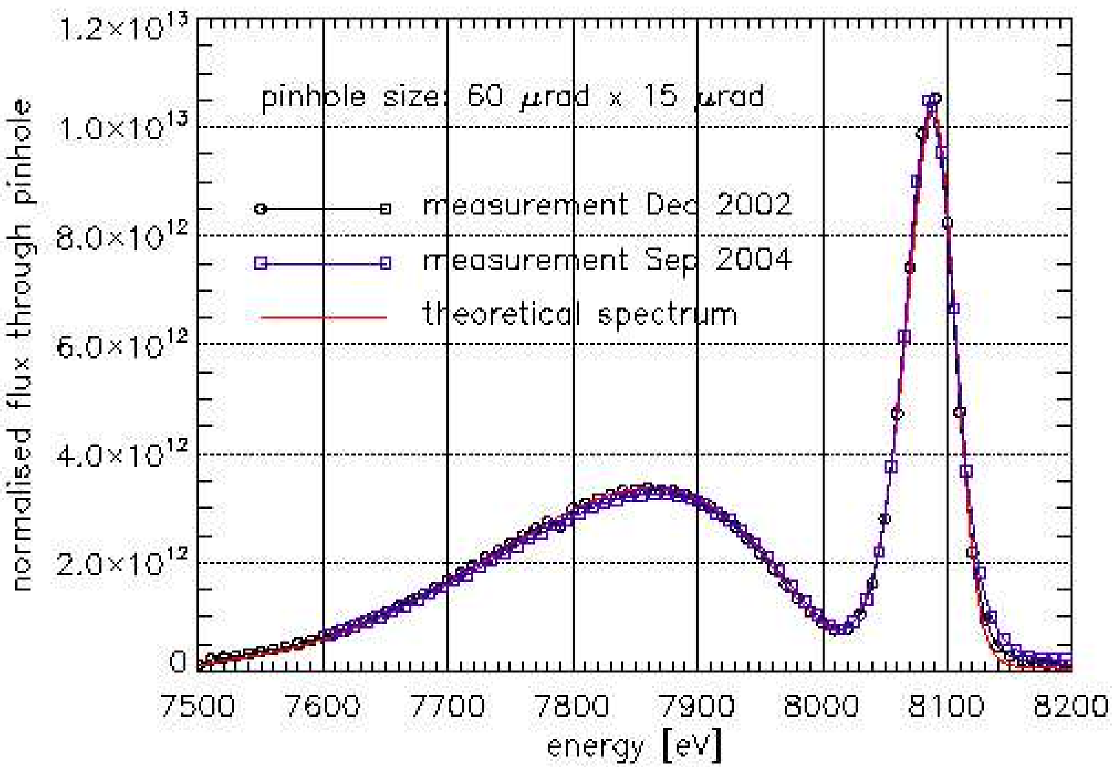
2.4 GeV & High Harmonic Operation: Undulator Radiation 4 - 18 keV





- **The SLS became the first medium energy user facility to rely on the high harmonic operation of small gap, short period undulators to reach $\simeq$ 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



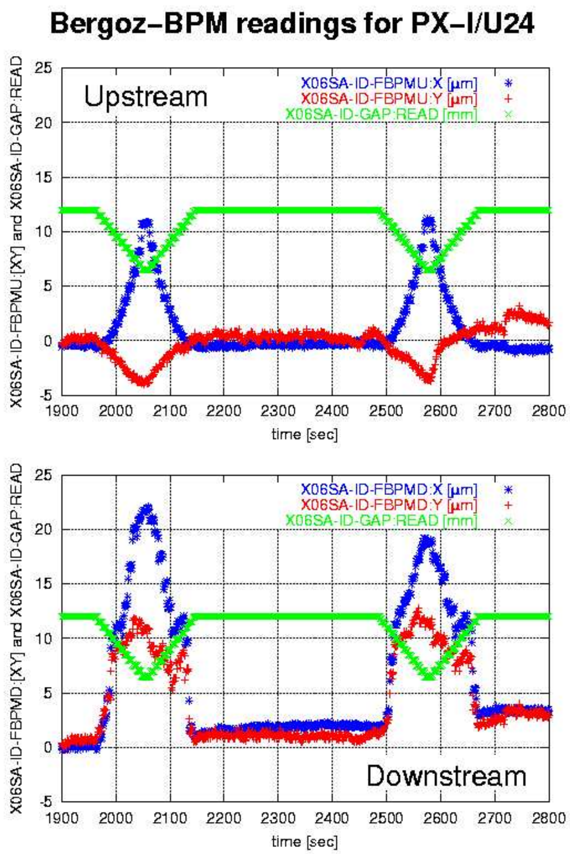
- **U24 measured spectrum (7th harmonic): no indication of radiation damage**
- **No change in spectral performance: 3.5 years of operation (ca. 2.5 years in top-up mode)**
- **Magnet: NEOMAX-32EH (not the most resistive material, see Bizen et al., SPring-8)**

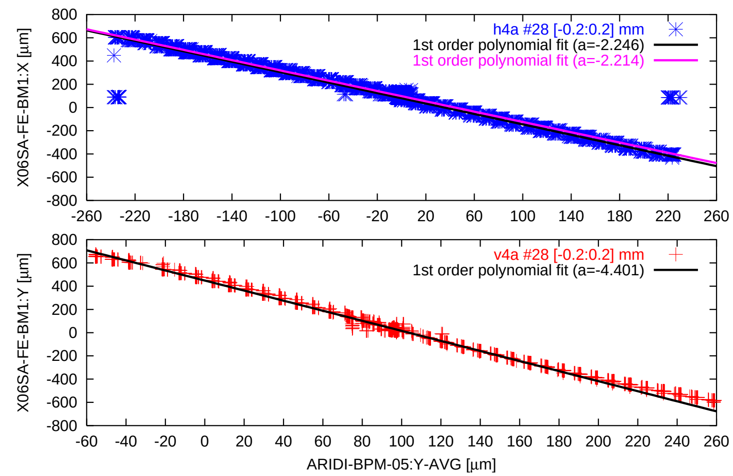
Magnet Materials

	Sumitomo I	Sumitomo II	Danfysik
Magnets	NdFeB	NdFeB	Sm_2Co_{17}
	NEOMAX-32EH	NEOMAX-27VH	RECOMA 28
Poles	Permendur	Permendur	Armco
Br	1.11 – 1.19 T	1.02 – 1.1 T	1.05 T
reached	1.158 T	1.095 T	
Hcj	> 30 kOe	> 36 kOe	25 kOe
nom/min gap	5/5.5mm	5/4.5 mm	5/4.5 mm
Beff	0.939 T	0.871 T	0.86 T
Keff	1.67	1.55	1.53

- **3 different magnet materials used: check possible radiation damage by spectral performance**

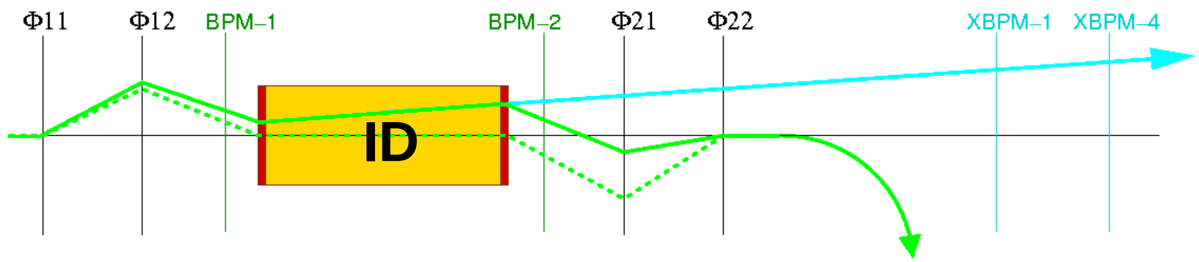
Impact on e-beam orbit & XBPM-calibration



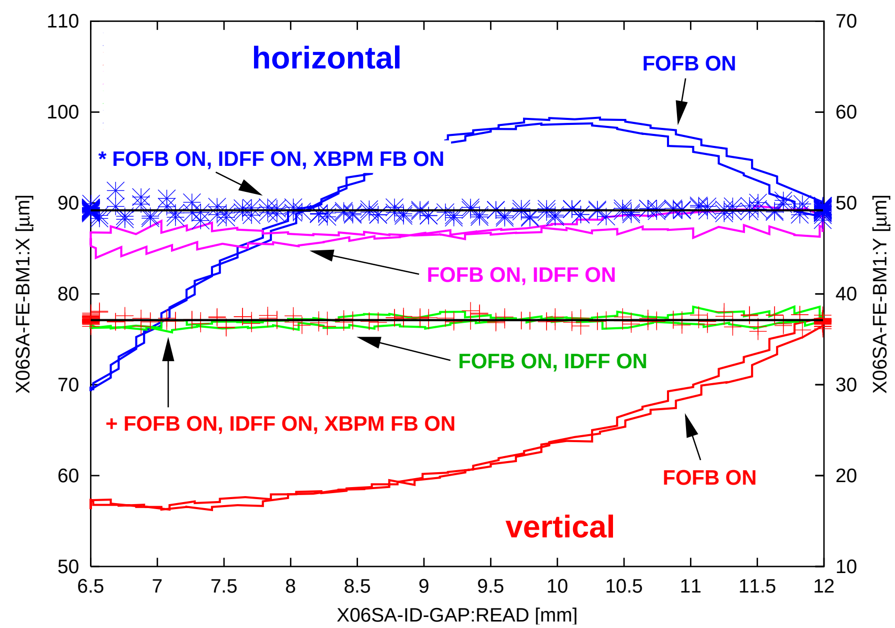


- **(a) FF and FOFB corrections switched off: change of local BPM readings with gap**
- **(b) XBPM calibration: linear dependence on parallel e-beam displacement in the undulator**

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



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

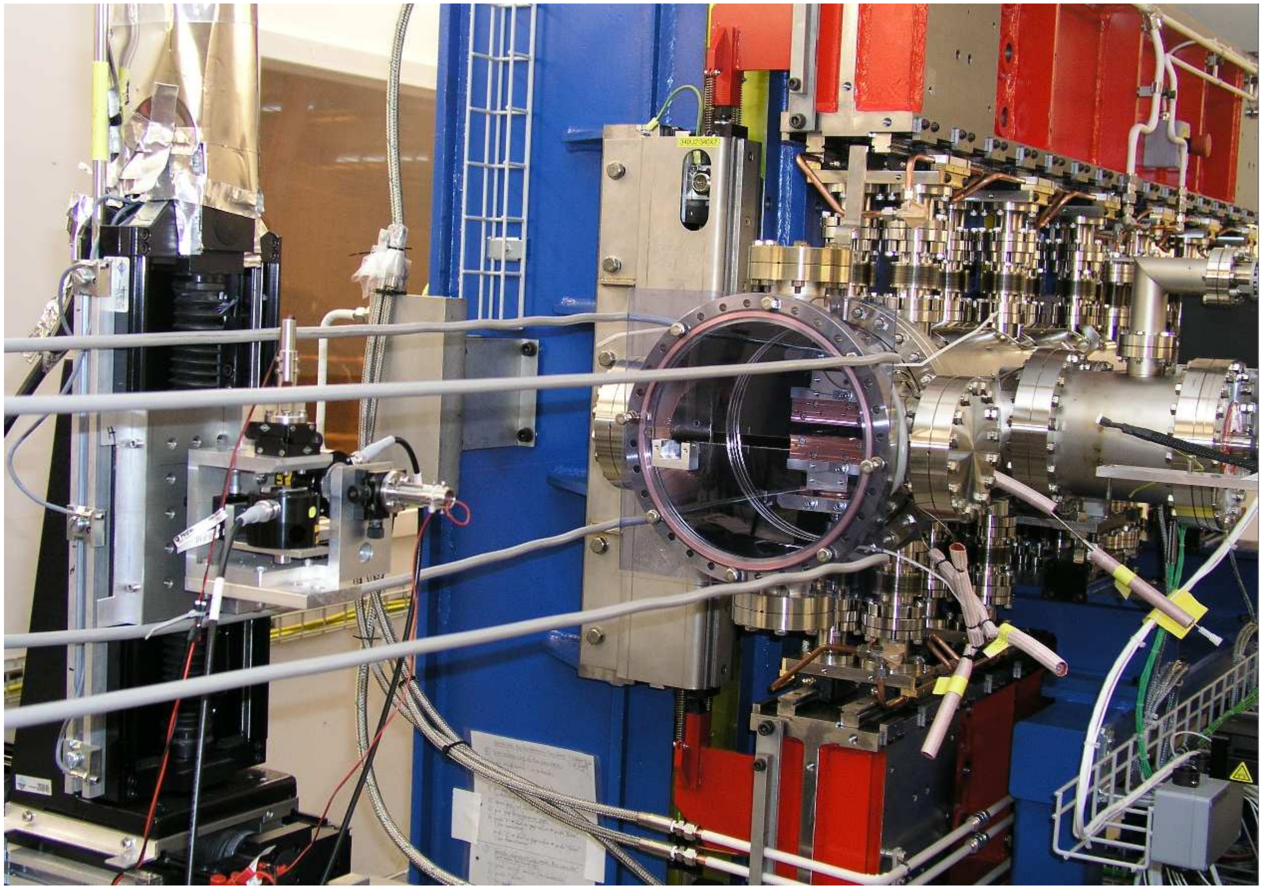


FOFB and ID-FF corrections: residual motion 1 μm (8.6 m distance from source point).

Undulator Construction: Vendor & PSI

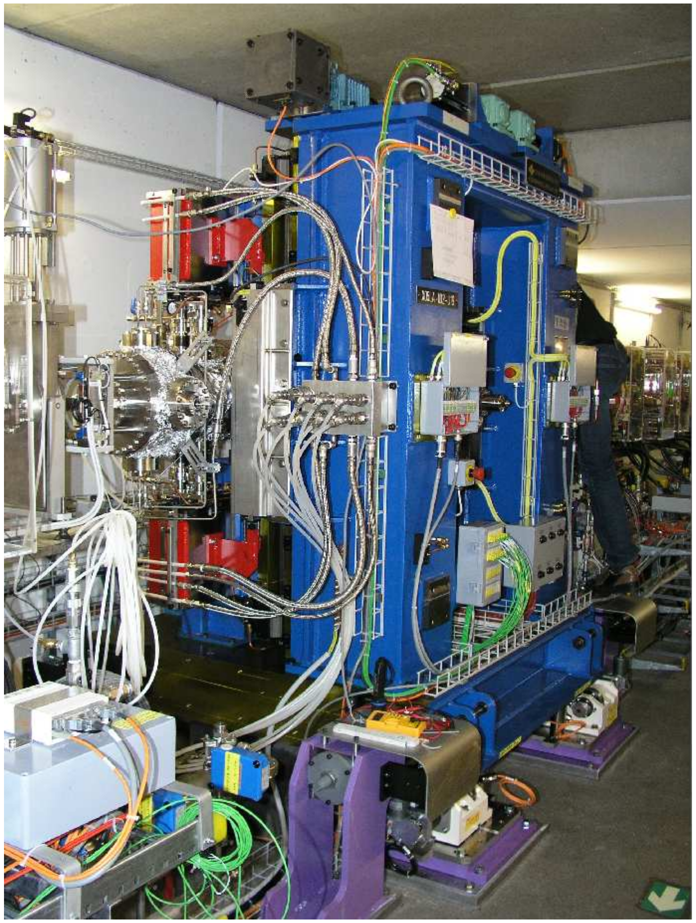
- Vendor (NEOMAX ⊕ DANFYSIK): mechanics, magnetics (+ mag. measurements), vacuum
- PSI: vacuum (taper transitions), electrics, control, alignment (mover), diagnostic+interlock

Undulator Magnetic Measurements: Stretched & Pulsed Wire



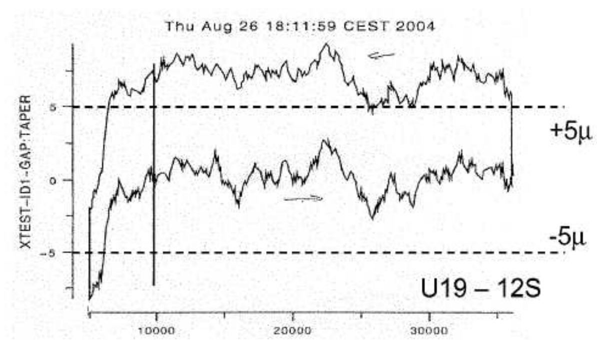
- **Magnetic measurements after delivery: 1st & 2nd integral (stretched wire) and trajectory straightness (pulsed wire)**

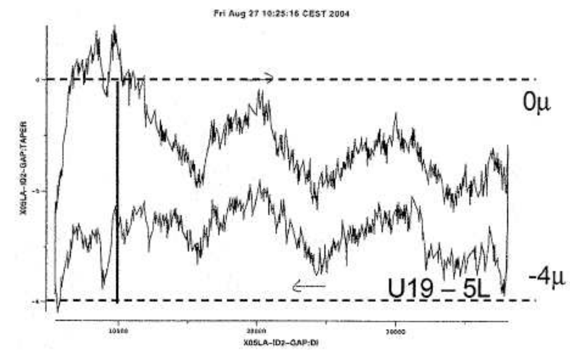
U19 In-Vac Undulator: Installion at the SLS Storage Ring



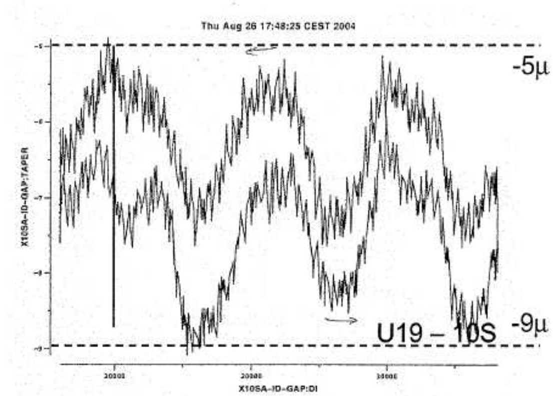
- In-situ alignmnent ($\leq$50 μm): undulator installed on mover system
- Gap-reading: linear encoders (shielded) attached to the outer backing beam

U19 Undulators: Mechanical Precision - Gap Taper



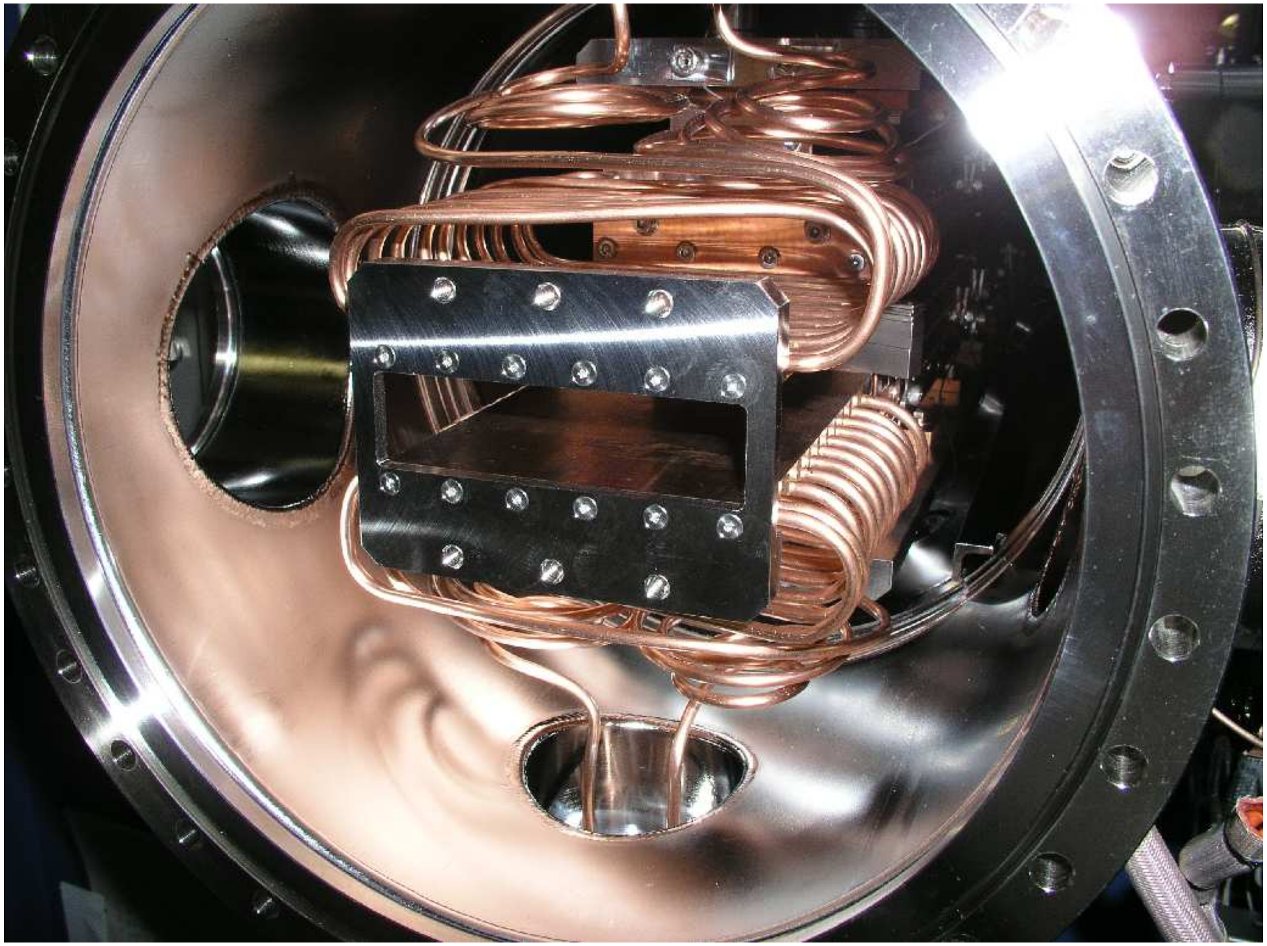


- All undulators driven with 1 motor
- Hysteresis and strong variation in tuning range at specs limit
- with 2 motor option: zero taper



- **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 $\simeq 1\ \mu$m)**

Flexible Taper Transitions



- 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)

Conclusions

- 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