SLS Status and Development of an SLS2 Upgrade

Michael Ehrlichman, Masamitsu Aiba, Michael Böge, Angela Saa-Hernandez, Andreas Streun
Paul Scherrer Institut, Villigen, Switzerland

ESLS XXII meeting, Grenoble, Nov. 2014
SLS in 13\textsuperscript{th} year of user operation: 18 beam lines

Performance 2014 (Jan.-Oct.)

Availability 97.2 %

MTBF 122 h

Two Major Incidents:
- U14 Broken Taper Foil, 76 hrs downtime
  - Located by activation
- 1-Second power outage, 65 hrs downtime
  - Helium compressor shut-off, partial warming of 3HC.
BPM system replacement

- New SLS BPM electronics
  - In-house design
  - Synergy with SwissFEL & E-XFEL (BPM FPGA board hardware, firmware, software, etc.)
  - Prototype: <100nm RMS noise at 2kHz BW (k=10mm geometry factor).
- New FOFB
  - Global BPM data transfer, one feedback engine (present system: 12 sector FBs communicating with adjacent sectors, 4KHz correction rate), more robust.
  - All feedback algorithms implemented low-level (DSP/FPGA) with ~10kHz correction rate (now: dispersive correction & photon BPM FB on high-level PC with few Hz correction rate).
  - Feedback algorithm in high-level language (presently: DSP assembler) provides better performance and allows adding new features:
    - Integration of coupling correction in FOFB: “2nd order orbit correction”.
    - Fast polarization switching for PolLux and PEARL. Now: Slow reference to FOFB & feed forward for coupling.
- Schedule
  - Replacement 2016/17 (team presently busy with SwissFEL & E-XFEL BPMs & feedbacks).

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1 “Development of New BPM Electronics for the Swiss Light Source”, W. Koprek, IBIC2012
SLS FOFB: Feedback Loops

Present System

Future System

Part of BPM (Calc: X,Y,...)

EPICS IOCs / VME Crates

DSP Boards

Digitizer/DDC Boards

RF Front-Ends

Button Pickups

Corrector Magnets

Beam Dynamics Server PC

Control Room GUI PCs

Power Supply Interface Board

Corrector Power Supplies

“Stupid”: Sends 4 amplitudes

FOFB electronics

Fast LOCAL feedback loop (4kHz): Each DSP gets only data from 18 BPMs.

Slow GLOBAL feedback loop, few Hz: (RF frequency & horizontal dispersion correction)

Just for FOFB Algorithm

EPICS IOCs / VME Crates

DSP Board

Power Supply Interface Board

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Intelligent/autonomous (XY, FFT, Fault Detect, FOFB Interface, ...)

Fast GLOBAL feedback loop (10-20kHz): New global real-time network.

Boris Keil, PSI, SYN-GFA Meeting
Motivation for an SLS2 Upgrade

• SLS commissioned in 2000
  – Serving 18 beamlines with >97 % uptime
  – 5.5 nm x 5 pm emittance beams at 400 mA

• New, state-of-the-art machines coming online
  – MAX-IV, NSLS2, ESRF Upgrade, PETRA 3, et. al.

• Need to stay competitive

• Project Goals
  – Replace SLS with significantly lower emittance design
  – Maintain existing building, injector, beam lines
  – Minimize downtime and impact to users
  – Moderate budget (<100 MCHF)
Storage rings in operation (●) and planned (●). The old (—) and the new (—) generation.

The storage ring generational change

Riccardo Bartolini (Oxford University)
4th low emittance rings workshop, Frascati, Sep. 17-19, 2014
SLS-2 design constraints and the main challenge

- **Constraints**
  - keep circumference: hall, tunnel.
  - re-use injector: booster, linac.
  - keep beam lines: avoid shift of source points.
  - limited “dark time” for upgrade.

- **Challenge: small circumference**
  - Scaling MAX IV to SLS size and energy gives $\varepsilon \approx 1$ nm.
  - Multi bend achromat: $\varepsilon \propto (\text{number of bends})^{-3}$
  - Damping wigglers (DW): $\varepsilon \propto \frac{\text{ring}}{\text{ring} + \text{DW}}$ radiated power
  - Low emittance from MBA and/or DW requires space!
Compact low emittance lattice concept

- Longitudinal gradient bends (LGB): field variation $B = B(s)$
  - $\varepsilon \propto \int (\text{dispersion}^2 \ldots) \times (\text{B-field})^3 \, ds$
  - high field at low dispersion and v.v.

- Anti-bends: $B < 0$
  - matching of dispersion to LGB
  - factor $\approx 5$ lower emittance compared to a conventional lattice

- Additional benefits
  - Hard X-rays ($\approx 80$ keV) from B-field peak ($\approx 5$ Tesla)
  - $\varepsilon$-reduction due to increased radiated power from high field and from $\Sigma|\text{angle}| > 360^\circ$ (“wiggler lattice”)

A compact low emittance cell

- Conventional cell vs. longitudinal-gradient bend/anti-bend cell
  - both: angle 6.7°, \( E = 2.4 \text{ GeV} \), \( L = 2.36 \text{ m} \), \( \Delta \mu_x = 160° \), \( \Delta \mu_y = 90° \), \( J_x \approx 1 \)

  conventional: \( \varepsilon = 990 \text{ pm} \)

  LGB/AB: \( \varepsilon = 200 \text{ pm} \)

\[ \beta_x \quad \beta_y \]

\[ \text{Disp.} \]

\( \text{at} \ R = 13 \text{ mm} \)

\[ \text{dipole field} \quad \text{quad field} \quad \text{total field} \]
Lowest emittance Prototype

- Maximal application of longitudinal gradient bend/anti-bend cell concept

Quadrupole:  
SC Longitudinal Gradient Bend:  
Longitudinal Gradient Bend:  
Anti-Bend:  

\[ \Sigma |\Phi| = 460^\circ \]

Peak B field: 5.7 T

\[ \beta_{x,\text{min, sb}} = 0.06 \, \text{m} \]
\[ \beta_{x,\text{min, else}} = 0.15 \, \text{m} \]
Comparison

<table>
<thead>
<tr>
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• Nonlinear momentum compaction makes this cell unfit for the SLS2 upgrade.
Longitudinal Dynamics

- Lattice is below transition.
- Momentum compaction is dominated by nonlinear terms.
- Goal: ±5% bucket.
- Limits injection scheme options.
- Manipulation of momentum compaction by multipoles seems to always require too large a sacrifice in DA.

\[ \frac{dz}{dp} = 0.0155 \]
\[ \frac{d^2z}{dp^2} = -0.339 \]
\[ \frac{d^3z}{dp^3} = 0.149 \]
\[ \frac{d^4z}{dp^4} = -5.609 \]

Bucket size limited by non-linear roll-off in momentum compaction

+z is head of bunch
Large Chromatic Tune Shifts

- Sextupole scheme that yields acceptable on-momentum DA, results in a large chromatic tune footprint.
Large Positive $\alpha_p$ Prototype

- Adjust optics for finite dispersion in ordinary bends to generate large positive $\alpha_p$.

\[ \Sigma |\Phi| = 391^\circ. \]
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Emittance reduction not as impressive
α_p is better
Challenging nonlinearities
Large Negative $\alpha_p$ Prototype

- Large dispersion in anti-bends generates large negative $\alpha_p$.

$$\Sigma |\Phi| = 506^\circ$$
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- Acceptable DA & **tune shifts** not found when using local optimizer on NDTs.
- Off-momentum DA is esp. important (+/- 5%).
- Now working with multi-objective genetic optimizer.

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**Relaxed optics**

Better $\varepsilon_x$

$\alpha_p$ is linear
7BA Superbend Cell (preliminary)

- 7BA constructed of superbends and antibends.
- Cancelation of 1\textsuperscript{st} order driving terms.
- Increased radiation.
- Weaker SC field required (4.5 T).

SC Longitudinal Gradient Bend: \(\)  
Anti-Bend: \(\)

\[ \sum |\Phi| = 504^\circ \]
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- 7BA Superbend cell is very preliminary.
- 60 superbends will be more expensive than 12.

Better $\varepsilon_x$
Good $\alpha_p$
Relaxed linear optics
Vertical nonlinearities challenging
IBS in Anti-Bend LGB Cell

- IBS is nonlinear, but for high-$\gamma$, a rough scaling is\(^1\):
  \[
  \frac{1}{\tau_{\text{IBS}, \perp}} = \frac{H_x}{\beta_x \sqrt{\beta_x \beta_y}}
  \]

- Can be mitigated by round beam scheme (1/2 the emittance).

- Only weakly dependent on RF, due to current requirements.

\[\text{Table: Prototype Lattices}\]

<table>
<thead>
<tr>
<th>Prototype Lattices</th>
<th>Zero Current Radiation Only $\varepsilon_x$</th>
<th>5 mA, 100 MHz 5% Bucket, 3HC (2x BL) 10 pm $\varepsilon_y$ $\varepsilon_x$</th>
<th>1 mA, 500 MHz 5% Bucket, 3HC (2x BL) 10 pm $\varepsilon_y$ $\varepsilon_x$</th>
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<tr>
<td>Concept</td>
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<td>LGB 7BA</td>
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<td>143 pm</td>
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\(^1\)A. Fedotov. “Comments on simplified treatment of intrabeam scattering using plasma approach.”, 2004
Injection Schemes

- **Goals:**
  1. Minimize user impact during top up
  2. Compact layout
  3. Minimize DA requirements
- “4 kicker” scheme meets none of these goals
- Longitudinal injection
  - Potentially meets all three goals.
  - Challenges
    - Requires “golf club” acceptance
    - Requires big momentum acceptance
    - Technological hurdles if 500 MHz used
- Multipole kicker injection
  - Possible solution, but off-axis, requires larger DA
- **Investigating hybrid approach**
  - Use multipole kicker to kick off-momentum particle onto dispersive closed orbit.
  - Near-on-axis, off-momentum.

Bunch injected on-axis, but onto “golf club” shaft in front of stored bunch.
**SLS-2 Design Research**

- **Find cell design** that gives sub-200 pm emittance and allows for acceptable DA and tune shifts.
- **Design & prototyping of SC Superbends.**
- **Study machine impedance**, decide on RF system.
  - Perhaps negative chromaticity with negative momentum compaction will also suppress head-tail & coupled bunch.
- **Explore round beam schemes.**
  - Split the emittance, makes IBS negligible
  - Round beam desired by most users.
- **Develop orbit feed-back based on photon BPMs.**
  - Carry over from SLS BPM Upgrade Project.
  - Lattice too dense for placing RF-BPMs at all locations.
- **Explore on-axis injection schemes.**
- **MOGA and PSO** for direct optimization of dynamic aperture.
  - Assisted by NDT calculations.
Conclusion

- SLS-2 design is constrained by comparatively small ring circumference.
- New LGB/AB cell provides a solution for compact low emittance rings.
- An emittance of 100-200 pm seems possible with contemporary magnet technology.
- But feasibility has not yet been proven.
- Project is in Concepts & Research phase.
- A conceptual design report is planned for 2016.