Status of Short X-ray Pulse (SPX) Project at the Advanced Photon Source

Ali Nassiri
On behalf of APS-U SPX Technical Team
Accelerator Systems Division

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Outline

- Transverse RF Chirp Concept
- Ultrafast Science with SPX
- SPX Technical Components
- Performance Parameters
- R&D Plan
- Summary
Transverse Rf Chirp Concept\(^1\)

**Baseline**: 2 MV deflecting voltage, ~2ps (FWHM) x-ray pulses

- **Input Coupler**
- **LOM Damper**
- **HOM Dampers**

**RFdeflectingcavity**

Cavity frequency is harmonic \( h \) of ring rf frequency

Ideally, second cavity exactly cancels effect of first if phase advance is \( n \times 180 \) degrees: "outside" users nominally unaffected

Radiation from tail electrons

Radiation from head electrons

Pulse can be sliced or compressed with asymmetric cut crystal

**Future Goal**: 4 MV deflecting voltage, ~1ps (FWHM) x-ray pulses

1 A. Zholents et al., NIM A 425, 385 (1999).
Ultrafast Science with SPX

- SPX is a new generation of ultrafast x-ray source that can probe matter with nanometer and picosecond precision. World’s first high average, **high repetition rate, tunable, polarized ultrafast x-ray source for a variety of applications in chemistry, materials, atomic & molecular physics and biology**

- It enables time-resolved x-ray scattering at the picosecond timescale while retaining the powerful characteristics of synchrotron radiation.


- **Picosecond timescale is ideal to probe dynamics in nano-scale systems which evolve at the speed of sound ~1nm/ps.**
SPX Technical Components

- Two cryomodules, each with 4 SC deflecting cavities equipped with:
  - Tuner with warm motor and piezo
  - LOM/HOM dampers
  - Precision cavity alignment

Dish Head
Saddle

JLab scissor jack style

4-wedge damper design
Peak power density: 42 W / cm³

Mark I (“baseline”)
Mark II (“alternate”)

SPX deflecting cavities, **THP212**, G.Waldschmidt

21mm x 120mm

Helium vessel riser will be sized for heat load
Helium volume 9.4 L

High precision actuators each end of cavity for vertical “Y” motion (1mm)

Precision alignment concept

Nitronic rods for fixed “X” direction

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SPX Technical Components (2)

A cryoplant for 2.0K operation

- Refrigeration @ 2.0K (4 MV) 320 W with 100% capacity margin
- Refrigeration @ 5-8 K for dist. & intercepts 500 W
- LN2 is planned for 80K shield cooling 4 kW

High-power rf system based on 10-kW CW klystrons
  - One klystron per cavity

Low-level rf system capable of delivering required amplitude and phase stability
  - Primarily regulate the amplitude and phase of the SPX deflecting cavity fields
  - Engineering and production of LLRF system for 8 cavity installation

Diagnostics
  - Measure beam tilt inside and outside SPX zone
  - Measure beam arrival time with respect to a phase reference and provide this information to low-level rf controls.
  - Cerenkov detectors/loss monitors to protect cavities

X-ray detector is the key to Beam Arrival Time array tilt monitor
Need fast (sub-ns rise time, low-intensity dependence – Diamond a good candidate
Initial test with polycrystalline diamond detector
  - rise time ~160 ps

Example: ELBE Cryoplant
220 W@ 1.8K + 200 W @80K
Single-Bunch and Multi-Bunch Stability Result

- SPX system in 24-singlets (4 mA per bunch) does not degrade the performance of single particle dynamics.
- Q's of longitudinal and transverse planes are very low (20 -800)
- Based on current operations coherent damping is applicable here
- Transverse plane would be stable in baseline number of cavities (8)
- Recent work demonstrates the possibility of “adjusting” hybrid pattern to reduce the worst-case growth rate

<table>
<thead>
<tr>
<th>Plane</th>
<th>Growth Rate</th>
<th>Damping Rate</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Synchrotron Radiation</td>
<td>Coherent</td>
</tr>
<tr>
<td>Longitudinal</td>
<td>30 s⁻¹</td>
<td>208 s⁻¹</td>
<td>Not applicable</td>
</tr>
<tr>
<td>Horizontal</td>
<td>180 s⁻¹</td>
<td>104 s⁻¹</td>
<td>&gt;600 s⁻¹</td>
</tr>
<tr>
<td>Vertical</td>
<td>125 s⁻¹</td>
<td>104 s⁻¹</td>
<td>&gt;600 s⁻¹</td>
</tr>
</tbody>
</table>

1 L. Emery, Y-C. Chae

Symmetric 202 mA in 24 bunches
153 ns spacing

0.5 μs train
186 mA in eight septuplets (8x7)
1.594 μs gaps

16 mA
Cavity Impedance Budget

Monopole Stability Threshold:

\[ R_s * f_p < 0.5 \text{M} \Omega - \text{GHz} \]

Dipole Stability Threshold:

\[ R_t < \frac{1.5 \text{M} \Omega}{m} \text{ Horizontal dipole} \]
\[ R_t < \frac{4.5 \text{M} \Omega}{m} \text{ Vertical dipole} \]

Cavity to cavity coupling will be tuned to meet stability specification for a single horizontal dipole mode.

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## Tolerances from Beam Dynamics Simulations\(^1\)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Baseline</th>
<th>Future Goal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Common mode amplitude variation(^1)</td>
<td>&lt;1%</td>
<td>&lt;1%</td>
</tr>
<tr>
<td>Common mode phase variation(^2)</td>
<td>&lt;4.8 deg</td>
<td>&lt;4.8 deg</td>
</tr>
<tr>
<td>Voltage amplitude mismatch between cavities(^3)</td>
<td>&lt;0.8%</td>
<td>&lt;0.4%</td>
</tr>
<tr>
<td>Voltage phase mismatch error between cavities(^4)</td>
<td>&lt;0.14 deg</td>
<td>&lt;0.07 deg</td>
</tr>
</tbody>
</table>

\(^1\) Keep intensity and pulse length variation under 1% rms.
\(^2\) Keep intensity variation under 1% rms.
\(^3\) Keep rms emittance variation outside SPX region under 10% of nominal 35 pm.
\(^4\) Keep rms beam motion outside of SPX region under 10% of beam size/divergence.
Conceptual System Design Approach

- **Common Mode Strategy**
  - Main RF used to lock beam to MO via Beam Arrival Time diagnostic
  - BPM Array 1 corrects for common mode phase error < 100 Hz
  - Deflected Tilt Monitor corrects for common mode amp error < 100 Hz
  - SPX RF system responsible for noise spectrum > 10Hz

- **Differential Mode Strategy**
  - Orbit Feedback (BPM Array 2) controls differential phase error < 100 Hz
  - Residual Tilt Monitors control differential amp error < 100 Hz
  - SPX RF system responsible for noise spectrum > 10Hz

C.M. amp variation <1%
C.M. phase variation <4.8 deg
D.M. amp variation <0.4%
D.M. phase variation < 0.07 deg
R&D Status

- Baseline cavity tests performed at JLab. It meets rf performance with 10% safety margin on deflecting voltage.

  Contributed talk, **WE OBS13**, H. Wang

- Fabrication of the “alternate” cavity is underway at JLab.

- Design of a cryomodule and ancillary components including dampers, tuner, precision alignment system have started.

- Collaborative work with LBNL on the development of low-level rf controllers and precision timing and synchronization system have started.

  - On-going effort on lattice development, beam dynamics, collective effects
  
  - Installation in ring of a 2-cavity cryomodule is planned for a single sector test.
    
    - Address risks that cannot be addressed by off-line experiments
    
    - Chirp is sufficiently well-defined to allow proof-of-concept for x-ray pulse length reduction.

Plot courtesy of H. Wang, JLab
Summary

- Short x-ray pulse generation using SC rf deflecting cavities gives much higher average flux compared to other schemes:
  - Laser slicing
  - Low-$\alpha$ operation
  - RF phase modulation
  - Harmonic cavity

- SPX should provide $\sim$2 ps FWHM or less x-ray pulses to
  - 3 insertion devices and 2 bending magnets beam lines

- Single-sector test should allow us to have an early look at chirped x-rays and address additional risks.

- R&D tasks are progressing well.

- Collaboration with JLab and LBNL is off to a great start.

- We are very excited and looking forward to proof-of-concept demonstration in 2013.
Acknowledgements

Thanks to the following people for their contributions:


**LBNL:** J. Byrd, L. Doolittle, G. Haung

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