

## STATUS OF THE SHORT-PULSE X-RAY (SPX) PROJECT AT THE ADVANCED PHOTON SOURCE (APS)\*

A. Nassiri<sup>#</sup>, N. Arnold, T. Berenc, M. Borland, D. Bromberek, Y-C. Chae, L. Emery, G. Decker, J. Fuerst, A. Grelick, D. Horan, F. Lenksuzs, R. Lill, V. Sajaev, T. Smith, G. Waldschmidt, G. Wu, B. Yang, A. Zholents, ANL, Argonne, IL 60439, U.S.A  
G. Cheng, C. Ciovati, J. Henry, P. Kneisel, J. Mammoser, R. A. Rimmer, L. Turlington, H. Wang, TJNAF, Newport News, VA 23606,  
J. Byrd, L. Doolittle, G. Haung, LBNL, Berkeley, CA 94720, U.S.A.

### Abstract

The Advanced Photon Source Upgrade (APS-U) at Argonne includes implementation of Zholents' rf deflection concept [1] for production of short x-ray pulses. This is a joint project between Argonne National Laboratory, Thomas Jefferson National Laboratory (JLab), and Lawrence Berkeley National Laboratory. This paper describes performance characteristics of the proposed sources and technical issues related to its realization. Ensuring stable APS storage ring operation requires reducing the quality factors of both lower-order and higher-order-modes of the single-cell superconducting rf deflecting cavities that can achieve operating deflecting fields while providing needed damping of all these modes. The project team is currently prototyping and testing several promising designs for single-cell cavities with the goal of down selecting a design in the near future. Here we describe the approach undertaken and report the preliminary results.

### INTRODUCTION

The concept of using transverse superconducting rf deflecting cavities to produce high-repetition-rate picoseconds x-rays with the APS has been previously described [2, 3]. Briefly, two cavities are required: the first cavity to impose a chirp on the electron beam and a second cavity to cancel the effects on the electron beam of the first cavity. The cavities must have a deflecting mode frequency that is a harmonic  $h$  of the APS storage ring rf frequency, 352 MHz. A workable choice of  $h=8$  corresponds to a deflecting cavity frequency of 2815 MHz. R&D activities include design and prototyping of superconducting deflecting cavities and components, cryomodule, low-level rf, particle/optical beam diagnostics, and timing/synchronization.

### CAVITIES SYSTEM

Single-cell cavities have been selected for the SPX project to meet the storage ring impedance requirements. Four deflecting cavities, each providing 0.5 MV of vertical deflection, will be assembled into a cryomodule.

A combined deflection voltage of 2 MV makes it possible to generate  $\sim 2$ -ps x-ray pulses after time filtering the x-ray pulses using vertical slits. An identical second cryomodule with four cavities will be located at an appropriate downstream location to reverse the effect of crabbing of the first set of cavities, thus restoring the beam to its nominal orbit. Two versions of a single-cell rf deflecting cavity are being designed and fabricated; a "baseline" and an "alternate" design as shown in Fig. 1. Due to the strict damping requirements, strong coupling from the cavity to the damping waveguide is required. Both SPX single-cell cavity designs use a Y-end group similar to those on the JLab high-current cryomodules to damp higher-order modes (HOM). The lower-order mode (LOM) damper utilized a waveguide damper either on the beam pipe or on the body of the cavity cell. The latter design offers a more compact geometry with enhanced lower-order and higher-order mode damping. Details of the SPX deflecting cavity design is found in reference [4].

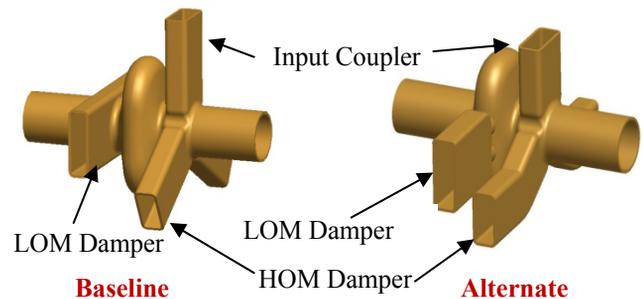


Figure 1: SPX deflecting cavity designs.

A prototype baseline cavity design was fabricated and tested recently at JLab. Test results indicate that the baseline cavity surpasses rf specifications for cavity Q and deflecting voltage by about 10% as shown in Fig. 2.

Fabrication of the prototype alternate cavity design is currently underway at JLab. Cavity down selection will be made after testing and qualification of the alternate cavity tuner design, precision cavity transverse alignment scheme, LOM/HOM damper concepts, and cryostat design.

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<sup>#</sup>nassiri@aps.anl.gov

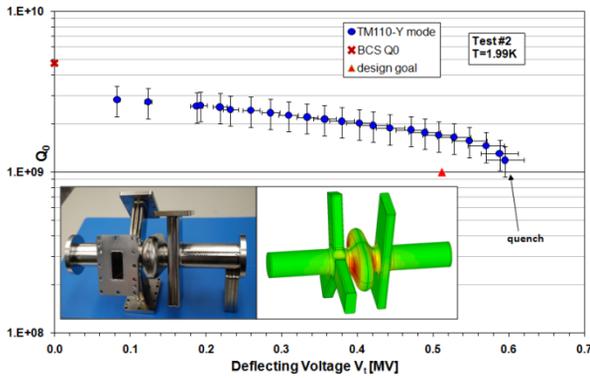


Figure 2: Vertical test result of baseline prototype cavity.

### HIGH-POWER RF SYSTEM

In phase one implementation, eight cavities (four per cryomodule) are used to provide a total deflecting voltage of 2 MV for 2-ps x-ray pulse generation. Each cavity will be powered by a conventional 10-kW klystron power amplifier. A common, ultra-low ripple, switch-mode, high-voltage power supply will provide power to the eight klystrons in each sector to minimize phase and amplitude noise, and to maintain coherent noise input to all amplifiers. In phase two (future upgrade), an additional four cavities will be added to each of the two cryomodule units with each cavity driven by its own rf amplifier to deliver a total deflecting voltage of 4 MV to produce 1-ps x-ray pulses. A schematic of rf system topology is shown in Fig. 3.

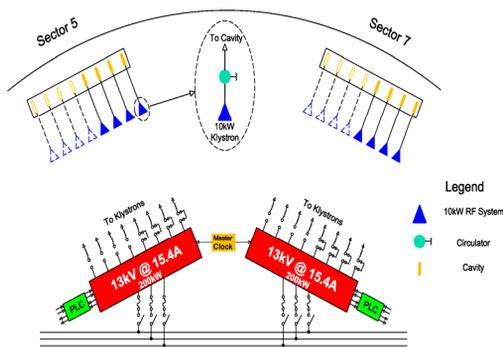


Figure 3: SPX high-level rf system topology.

### LOW-LEVEL RF, TIMING AND SYNCHRONIZATION

The SPX rms common mode tolerances are 1% and 4.8 deg while the differential rms tolerances are 0.5% and 0.07 deg. The differential phase error tolerance, driven by orbit stability requirements, will be especially challenging to the rf system. A conceptual design strategy using beam-based feedback is shown in Fig. 4 to suppress the low frequency noise. Beam position monitors outside the SPX zone will measure orbit distortions caused by differential phase errors and feedback to the phase of the downstream SPX sector.

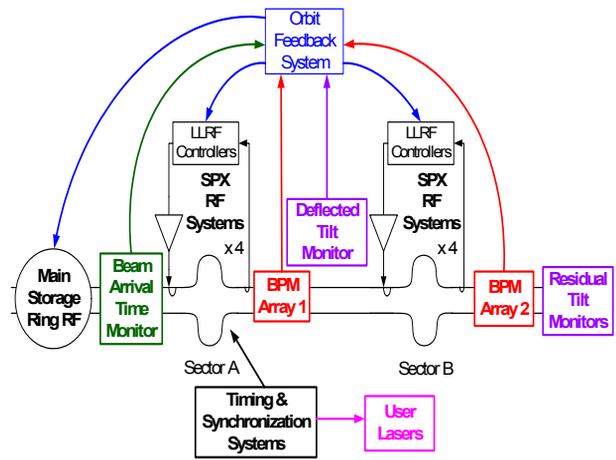


Figure 4: Beam-based feedback control concept.

Residual tilt monitors outside the SPX zone will be used to correct the amplitude of the downstream SPX cavity sector. To meet the common mode phase specification, a beam arrival time monitor (BAT) is planned to measure and feedback to the phase of the main SR 352MHz rf. Within the SPX zone a tilt monitor will be used to measure and correct common mode amplitude. The existing orbit feedback system has both proportional and integral control with a bandwidth of ~60 Hz. The rf system will be responsible for noise above ~10 Hz providing an overlap between the two systems that ensures complete spectral coverage. Digital LLRF control can be adopted for the rf systems due to its capability of white phase noise floors below -138 dBrad<sup>2</sup>/Hz, which, when integrated from 10 Hz to 1 MHz is equivalent to ~0.007 deg rms.

The beamline lasers need to be synchronized to a fraction of the x-ray pulse. For a 1-ps pulse width, the beamlines require that their lasers be synchronized to within 100 fs of the x-ray pulse arrival time. To accomplish this, femtosecond level stabilized fiber optic links [5] will be used to transfer the phase of the upstream SPX sector cavities to the users in order to lock their laser oscillators to the x-ray pulse production time. The timing/synchronization system will also provide all timing fiducials and phase references to the rf and beam diagnostics systems, such as beam arrival time, position, and tilt monitors.

### BEAM DIAGNOSTICS

The SPX will require six new beam position monitors (BPM) systems for positioning the electron beam to ± 50 μm of the deflecting cavities electrical centers. The trajectory of the beam through the centers of the deflecting cavities' is critical to minimize the effect of beam loading perturbations on stability budget. The BPMs will be critical for beam-based alignment and operations. There is one BPM upstream and one downstream of each set of deflecting cavities and one

BPM upstream and one downstream of the insertion device (ID) for a total of six.

The BAT monitor development will leverage off work previously accomplished for the APS linac phase stabilization. Similar to the linac phase stabilization the SPX will require a phase detection system to measure beam arrival time relative to the SPX crab cavity rf drive input and incorporate this data in an active feedback loop.

The rf tilt monitor required for SPX will leverage off work previously accomplished for the cavity BPMs designed for the LCLS project [6]. The tilt signal component is in quadrature with the beam position signal and is the result of the finite phase extension of the bunch. In addition to an rf tilt monitor, optical tilt monitors are also being designed. Two x-ray bunch tilt/arrival time monitors are being considered, one for the bend magnet line and one for the 7-ID undulator beamline. Each detector consists of an array of ultrafast detectors placed above and below the orbit plane. The difference in detector pulse arrival times gives information on the slope of the x-ray bunch and the average of the pulse arrival times gives information on the arrival time of the on-axis user beam pulse.

## BEAM DYNAMICS

An extensive study of the impact of the deflecting cavities on the beam dynamics in the APS was performed including the effects of errors [2]. In a recent study, it was found that the deflecting cavities make a substantial impact on the single-particle beam dynamics. The largest effect is most likely the vertical emittance increase due to particles with large vertical trajectories in the sextupoles between the two sets of cavities separated by two straight sectors. In the initial simulations, we have found that the vertical emittance increases by a factor of 20. After a careful study of the emittance growth, we found a way to control the emittance increase by adjusting sextupole strengths between the two sets of deflecting cavities. A sophisticated optimization was used to ensure sufficient dynamic and momentum apertures of the storage ring by varying the sextupoles strengths. In the final design, the emittance increase is kept below 20%. Furthermore, beam current-dependent effects were investigated to evaluate the impact of the SPX deflecting cavity which is the source of large impedance to the beam. The transverse impedance alone will reduce the single bunch current limit to below 16-mA, which is currently available to the APS users. However, since the longitudinal impedance of the SPX cavities has a significant bunch lengthening effect (see Fig. 5), the operation of the SPX cavities system will not affect a nominal 16 mA per bunch for the user operations. A second concern is the emittance degradation due to the impedance kick to the tilted beam slices in the vertical plane produced by the deflecting cavities. We have investigated the worst-case scenario for the 50-ps bunched beam at 6-mA current. Simulation results indicate a 3% increase in x-ray pulse due to the emittance increase by 10%.

## TEST STAND

A test stand is being assembled to allow bare cavity tests at 2.0 Kelvin at the ANL SRF facility. The existing SRF facility's refrigeration capacity at 2.0 K is increased from 20 W to as much as 70 W by adding an additional 2.5 g/s oil-injected vacuum system. Bare cavities will be tested in a vertically oriented LHe dewar fitted with a new neck insert and cryogenic feedbox. The test stand will be equipped with two mobile rf systems; a 300-W TWT rf amplifier and a 2815 MHz, 5-kW cw klystron amplifier.

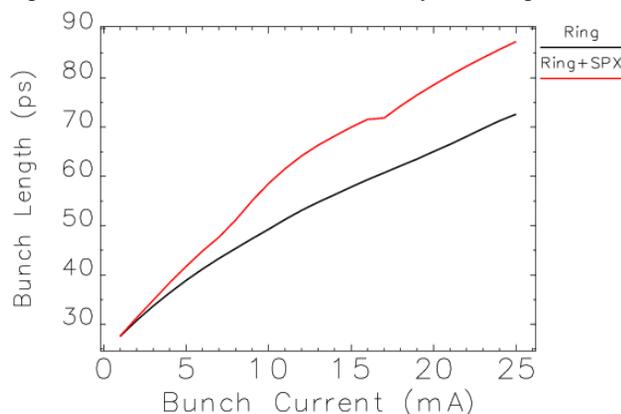


Figure 5: Bunch lengthening in the storage ring due to longitudinal impedance of deflecting cavities.

## SUMMARY

We have chosen an 8th harmonic deflecting cavity (2815 MHz) to achieve a rapid chirp with modest deflecting voltage of 2 MV. This provides a 2-ps x-ray pulse using slits, resulting in an approximately twofold reduction of intensity. We find that a 2-MV operation would have no significant impact on normal APS operation. R&D activities in cavity system, cryomodule, low-level rf, timing/synchronization, and diagnostics are progressing well.

## REFERENCES

- [1] A. Zholents et al., NIM A 425, (1999) 385.
- [2] M. Borland, Phys. Rev. ST Accel. Beam 8, (2005) 074001.
- [3] A. Nassiri, "Deflecting Cavities for Light Sources," ICFA Beam Dynamics Mini-Workshop of Deflecting/Crabbing Cavity Applications in Accelerators, SINAP, Shanghai, China, (2008).
- [4] G. Waldschmidt et al., "Superconducting Cavity Design for Short-Pulse X-Rays at the Advanced Photon Source," these proceedings.
- [5] R. Wilcox et al., "Stable Transmission of Radio Frequency Signal on Fiber Links using Interferometric Delay Sensing," Opt. Lett. 34 (20), (2009) 3050.
- [6] R. Lill et al., "Linac Coherent Light Source Undulator RF BPM System," FEL06, Berlin, Germany, p. 706 (2006).