SLAC-PUB-15756

STATUS OF THE SHORT-PULSE X-RAY PROJECT AT THE ADVANCED PHOTON SOURCE*

A. Nassiri#, N.D. Arnold, T. Berenc, M. Borland, B. Brajuskovic, D. Bromberek, J. Carwardine,
G. Decker, L. Emery, J. D. Fuerst, A. Grelick, D. Horan, J. Kaluzny, F. Lenkszus, R. M. Lill, J. Liu,
H. Ma, V. Sajaev, T.L. Smith, B. Stillwell, G. Waldschmidt, G. Wu, B. Yang, Y. Yang,
A. Zholents, ANL, Argonne, IL 60439, USA
G.G. Cheng, G. Ciovati, P. Dhakal, G. V. Eremeev, J. Feingold, R.L. Geng, J. Henry, P. Kneisel,
K. Macha, J.D. Mammosser, J. Matalevich, A.D. Palczewski, R. Rimmer, H. Wang, K. Wilson,
M. Wiseman, JLAB, Newport News, VA 23606, USA
J. Byrd, L. Doolittle, G. Haung, LBNL, Berkeley, CA 94720, USA
Z. Li, L. Xiao, SLAC, Menlo Park, CA 94025, USA

Abstract

The Advanced Photon Source Upgrade (APS-U) Project at Argonne will include generation of short-pulse x-rays based on Zholents' deflecting cavity scheme [1]. We have chosen superconducting (SC) cavities in order to have a continuous train of crabbed bunches and flexibility of operating modes. In collaboration with Jefferson Laboratory, we are prototyping and testing a number of single-cell deflecting cavities and associated auxiliary systems with promising initial results. In collaboration with Lawrence Berkeley National Laboratory, we are working to develop state-of-the-art timing, synchronization, and differential rf phase stability systems that are required for the Advanced Photon Source (APS) Short Pulse X-ray (SPX). A collaboration with the Advanced Computations Department at Stanford Linear Accelerator Center is looking into simulations of complex, multi-cavity geometries with lower- and higher-order-modes waveguide dampers using ACE3P. This contribution provides the current R&D status of the SPX project.

INTRODUCTION

We previously reported on SPX R&D in support of the APS Upgrade Project at Argonne [2]. The concept of using transverse superconducting rf deflecting cavities to produce high-repetition-rate picosecond x-rays with APS has been previously described [1-3]. Since our last report in 2011, substantial progress has been made in deflecting cavities prototyping and components, design of a 2-cavity cryomodule, low-level rf, timing/synchronization, beam diagnostics, and advanced electromagnetic simulations and analysis.

CAVITY AND CRYOMODULE

A combined deflecting voltage of 2 MV is required to generate ~2-ps x-ray pulses after time filtering the x-rays pulses using vertical slits. Two versions of a single-cell rf deflecting cavity (Mark I and Mark II) have been prototyped. Both designs use a Y-end group similar to those on the JLab high-current cryomodules to damp higher-order modes (HOMs). The lower-order modes (LOM) damper utilizes a waveguide damper either on the beam pipe (Mark I) or on the body of the cavity cell (Mark II). The latter design offers a more compact geometry with enhanced lower-order and higher-order mode damping. We have chosen the Mark II cavity (see Fig. 1) as the SPX baseline design. Details of the SPX cavity design is found in [4]. Recent vertical tests of the Mark II cavity at JLab indicate that it can surpass rf specification for deflecting voltage by about 10% but has a lower cavity Q. Further processing and testing is underway to improve cavity Q for the Mark II prototype cavity [5]. Vertical test measurement results of both prototype cavities are shown in Fig. 2.

Figure 1: A pair of SPX Mark II deflecting cavity.

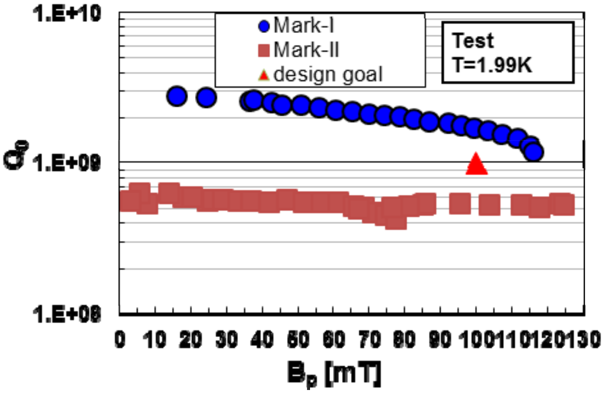

Figure 2: Mark I and Mark II vertical prototype cavity test results.

---

*Work supported by U.S. Department of Energy, Office of Science, under Contract No. DE-AC02-06CH11357.

nassiri@aps.anl.gov

Presented at the 3rd International Particle Accelerator Conference (IPAC 2012)
New Orleans, Louisiana, USA, May 20 - 25, 2012

Work supported in part by US Department of Energy under contract DE-AC02-76SF00515.

Along with cavities prototyping and testing, advanced simulation of the complete cryomodule with four cavities were performed. Simulations showed the damping of the unwanted rf modes met the SPX design requirement. Few modes are coupled and require special consideration. These modes are not believed to be harmful to stored beam but may cause additional heating of the beam pipe if they become trapped [5].

In the SPX R&D phase (SPX0), two Mark II deflecting cavities will be assembled into a short cryomodule equipped with two CEBAF scissor jack tuners, which will provide sufficient frequency tuning with 40-Hz resolution. An optional piezo tuner for each cavity is being considered to improve tuner resolution down to several hertz when needed.

For SPX0, two cavities will be paired and connected together to simplify the alignment design, which can achieve the required ± 200 μm in the vertical direction where beam deflecting is to occur. LOM/HOM damper prototypes have been fabricated. Testing is in progress to assess the effectiveness of bonding between rf absorbing material (silicon carbide) and its copper housing. Particulate generation and life time of damper prototypes assembly will be investigated afterwards [6].

An SPX cryomodule layout has been completed. Initial estimate of the total heat load will be less than 100 W per cryomodule. Figure 3 illustrates a cross section of the SPX cavity helium vessel assembly. A new design of low-impedance bellows was developed to connect cavity pairs in an SPX cryomodule [7]. The bellows allows ± 0.5 mm vertical movement to allow active alignment between cavity pairs.

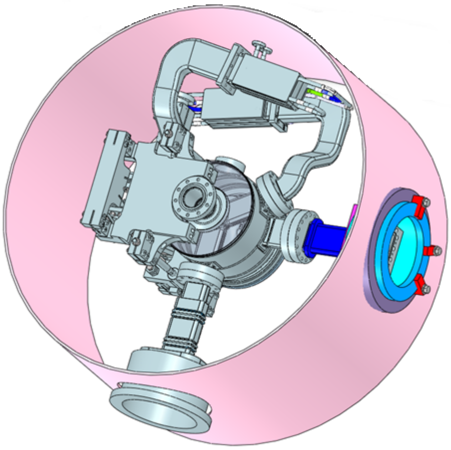

Figure 3: A cross sectional view of SPX cavity helium vessel, tuner, and HOM dampers.

RF SYSTEM

The SPX high-power rf system consists of two groups of four 10-kW cw klystron-based rf power amplifier systems, with each group powered by one high-voltage power supply in order to achieve a coherent noise contribution from the power supply among rf systems in each sector. Each 10-kW rf system is configured to drive a single rf deflecting cavity utilizing a WR284 waveguide transmission line. The waveguide transmission system also provides two directional couplers for system monitoring, a four-post tuner to adjust cavity loaded Q, and a waveguide absorptive filter that dissipates LOM and HOM power generated by the cavity. Each amplifier system includes a 50-kW isolator to absorb incident rf power reflected by the cavity, and also rf power generated by the cavity when driven by stored beam. Each 10-kW rf system includes a personnel safety interlock that monitors waveguide nitrogen pressure to protect against rf radiation hazards from loose or open flanges, and master slow and fast rf interlock systems for equipment protection of the amplifier and cryomodule components.

To support SPX R&D phase (SPX0), two test stands have been constructed, one for high-power testing of mode damper materials and designs, and one for vertical cavity tests. A 2.815-GHz, 4-kW cw rf system and associated test stand apparatus have been designed and built, as shown in Figure 4. This test stand is being used to provide rf power for waveguide window testing, and thermal cycling tests on HOM damper material bonding techniques. A vertical cavity test stand (see Figure 5) was assembled at the Argonne ATLAS test facility, and was used to confirm rf performance measurements on the first-article deflecting rf cavity produced for the SPX R&D program. The test stand utilized a 275-watt TWT amplifier to drive the cavity. Plans are underway to modify the SPX cavity test system at the ATLAS test facility to utilize a 5-kW cw amplifier to drive rf cavities and input couplers to full-field performance.

Figure 4: The 4-kW SPX rf test stand.

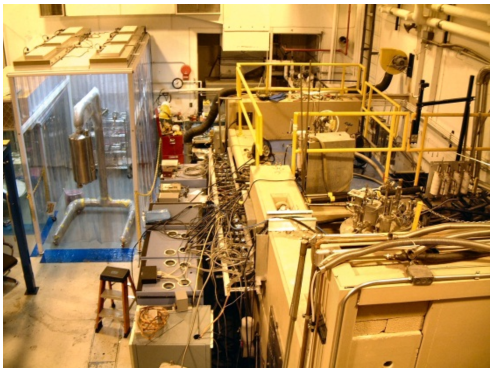

Figure 5: The SPX vertical cavity test stand at the ATLAS test facility.

SIGNALS AND SYSTEMS

The tolerances for the SPX cavity field have evolved and now are at 7% and 10 degrees for common mode variations and 1% and 0.077 degrees differential variation between sectors over the band of 0.01 Hz to 1 kHz. A working group is developing spreadsheets to apportion the overall tolerances to various systems and beam perturbations.

The tolerance for synchronizing beamline laser oscillators to the x-ray pulse is 400 femtoseconds. This is based upon keeping beamline resolution degradation due to jitter to below 10%.

Much of the collaboration effort with LBNL to date has concentrated on LLRF for SPX. Four LLRF receivers, two frequency generation chassis, and two cavity emulators have been fabricated. In addition, an improved receiver analog front end has been designed and prototyped. Figure 6 shows a test setup consisting of a frequency generation chassis, two LLRF receivers, two cavity emulators, and a residual phase noise measurement test set. Figure 7 shows the integrated differential phase noise between the outputs of the 2-cavity emulators while they were driven and controlled in a closed loop by the LLRF receivers.

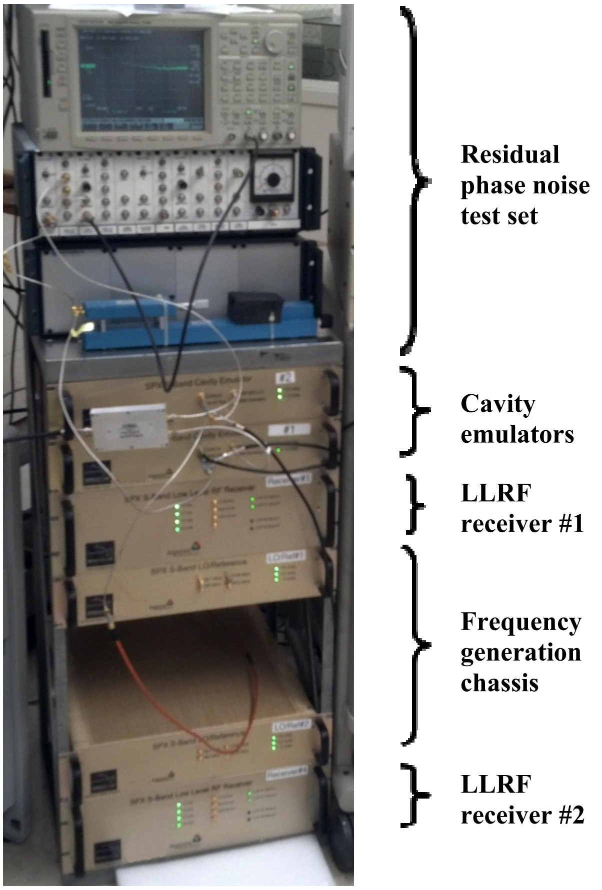

Figure 6: LLRF receiver/cavity emulator test setup.

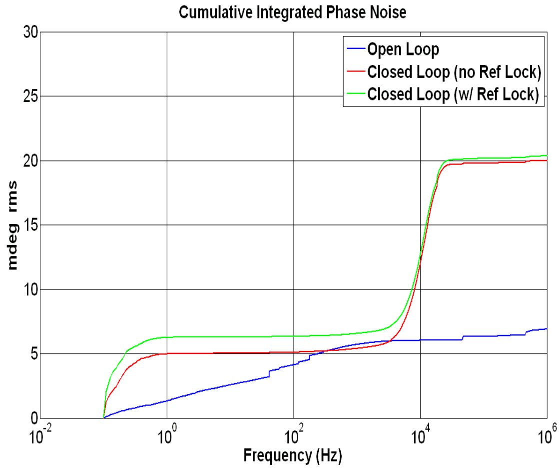

Figure 7: Phase noise measurement between 2-cavity emulators.

This preliminary measurement showed that the LLRF system itself has the capability of a 20-femtosecond rms noise floor over the band 0.1 Hz to 1 MHz. Studies of LLRF closed-loop noise suppression capabilities to suppress system disturbances such as microphonics and beam loading perturbations are being pursued through the R&D cavity testing program.

The differential phase tolerance of 77 millidegrees is very challenging.

We are presently implementing the LBNL-developed femtoseconds synchronization system [8] to synchronize the LLRF receivers and beamline lasers. We envision a 16-channel system with distributed link stabilizer chassis to provide the required phase references. Work is currently proceeding on integrating reference phase stabilizers into the LLRF receivers and designing laser oscillator controller/stabilizers

CONCLUSION

We continued to make progress on SPX R&D. Collaboration with JLab on cavity/cryomodule design and prototyping produced three prototype Mark II cavities for the SPX in-ring test (SPX0) and finalized the design of the SPX0 2-cavity cryomodule. Collaboration with LBNL on LLRF and timing/synchronization is progressing well. We continued to refine cavities electromagnetic simulations in collaboration with SLAC.

REFERENCES

[1] A. Zholents et al., NIM A 425, 385 (1999).
[2] A. Nassiri et al., WEOB35, PAC'11 (2011).
[3] M. Borland, PRST-AB 8, 074001 (2005).
[4] G. Waldschmidt et al., THP212, PAC'11 (2011).
[5] L. Xiao et al., "Higher Order Modes Damping Analysis for the SPX Deflecting Cavity Cryomodule," these proceedings.
[6] G. Waldschmidt et al., "High-power Waveguide Dampers for the Short-Pulse X-Ray Project at the Advanced Photon Source," these proceedings.
[7] G. Wu et al., "Low Impedance Bellows for High-Current Operations," these proceedings.
[8] R. Wilcox et al., Opt. Lett. 34(20), 3050 (2009).