THE ADVANCED PHOTON SOURCE PULSED DEFLECTING CAVITY RF SYSTEM

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Abstract

The Advanced Photon Source Deflecting Cavity System for producing short X-ray pulses uses two multi-cell, S-band cavities to apply a deflecting voltage to the stored electron beam ahead of an undulator that supports a beamline utilizing picosecond X-rays. Two additional multi-cell cavities are then used to cancel out the perturbation and restore the electron beam to its nominal orbit. The pulsed rf system driving the deflecting cavities is described. Design tradeoffs are discussed with emphasis on topology considerations and digital control loops making use of sampling technology in a manner consistent with the present state of the art.

BACKGROUND

The effort to produce short X-ray pulses at the Advanced Photon Source (APS) has been evolving in pursuit of the combined goals of maximizing performance while simultaneously minimizing both technical risk and disruptive effects on any existing activities of APS users [1,2]. The original approach [3,4] used superconducting rf (SRF) in order to achieve cw operation. This was later revised [5] to use three pulsed, normal-conducting cavities within a single sector. The current version has changed to two pairs of cavities located in two adjacent sectors. Figure 1 is a functional diagram of the Short X-ray Pulse (SPX) system.
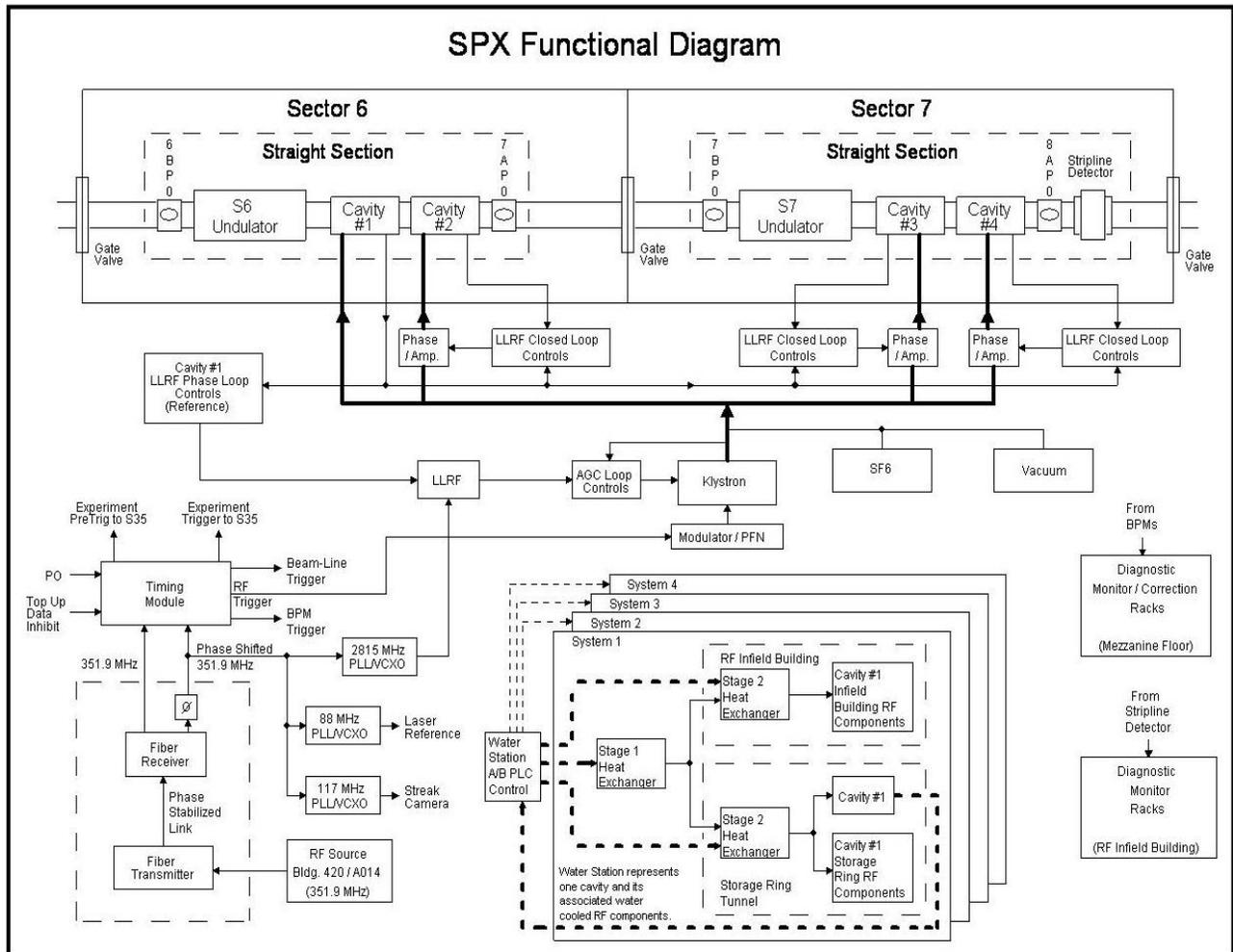
Figure 1: Configuration diagram.

CONFIGURATION

The Short X-Ray Pulse (SPX) rf system will use one klystron at 2815.5 MHz to deliver a peak rf power of up to 25 MW at a pulse width of 1.3 µs. The pulse repetition rate will initially be 120 Hz and, as higher performance hardware gets installed, will increase to 1 kHz. The rf power will be divided into four approximately equal parts by a waveguide variable power divider and two waveguide 3-dB hybrids. Each of the resulting four legs will feed approximately 2.8 MW into a three-cell, normal-conducting deflecting cavity [6,7] via a magic tee that provides two outputs that are 180º out of phase with one another. Cavity number 1 will have phase and amplitude closed loops within the low-level rf hardware and be phase locked to a timing reference. Cavities 2, 3, and 4 will each use both an electromechanical waveguide phase shifter to get a coarse initial setting and a waveguide ferrite IQ modulator to provide amplitude and phase closed-loop feedback in which each cavity will have its phase regulated so as to keep it phase locked to cavity number 1 in an effort to achieve a cavity-to-cavity phase stability requirement of 0.05°.

Cavities 1 and 2 will be installed in storage ring sector 6 and cavities 3 and 4 will be installed in sector 7. All rf components that are not inside the storage ring tunnel will be located in a new building constructed on the accelerator infield. Most rf components within the infield building will be pressurized with 3.1 bar SF6. Dual-redundant waveguide shutters will be used to provide isolation both to and from the storage ring. The rf infield building will be positioned to minimize waveguide run lengths, and therefore rf losses, as well as thermally induced differential phase drift. The waveguide run between the infield building and the storage ring tunnel will be under vacuum. There will be windows both where the waveguide changes environment before leaving the infield building and just before the cavity inputs, providing double isolation between SF6 and the storage ring.
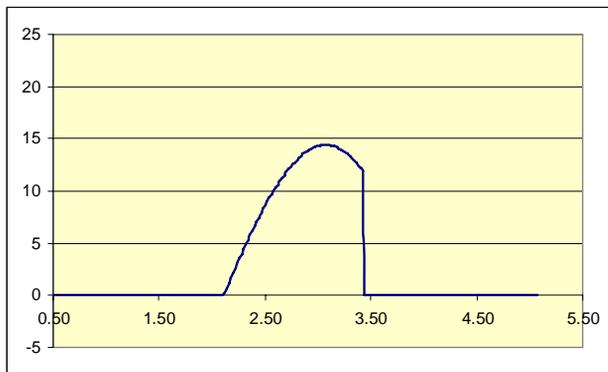
Figure 2: Calculated klystron output power (power in MW vs. time in µs).

PULSE CHARACTERISTICS

The width and shape of the rf pulses produced by the klystron have been subject to considerable review and discussion because of thermal issues regarding the deflecting cavities, klystron, and modulator, as well as other rf components, at the required pulse repetition rate of 1 kHz. All considerations dictate a pulse width of not more than 1.5 µs. The klystron pulse was originally assumed to be square, but the advantages of using a sinusoidal pulse instead are quite compelling. Average power dissipation in each component is reduced. The modulator pulse characteristic can be tuned to coordinate with cavity fill time such that modulator and rf system jitter have very little effect on the cavity amplitude and phase. Figure 2 shows a simulated sinusoidal klystron output pulse, and Figure 3 is an experimental result seen using an envelope detector.
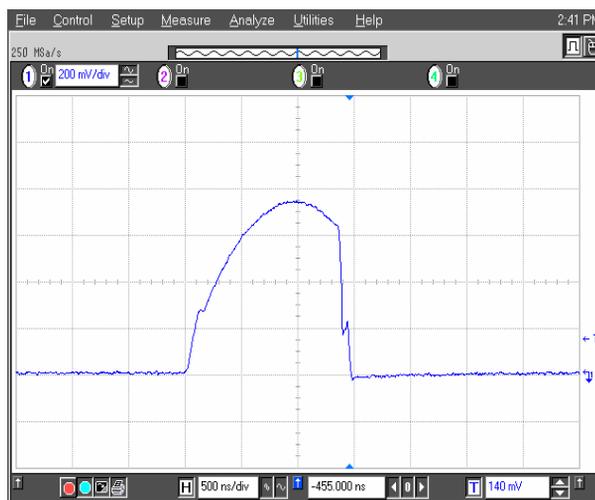
Figure 3: Measured klystron output power (forward power = 25 MW, PFN = 28.6 kV).

PHASE MEASUREMENT AND CONTROL

Cavity phase will be measured using 80 Ms/s digital sampling of a field probe signal that has first been down-converted to 20 MHz. An ultra-low-noise 20-MHz oscillator is used as the down-conversion IF reference and also as the source for deriving the sample clock. The immediate output of the sampling process is I and Q data, which are convertible to phase and amplitude. Each pair of field probe signals, which originate at a cavity pair that is to be held in accurate phase synchronization, is down converted, sampled and directly subtracted, minimizing any possible errors resulting from differences in electronics in the signal path.

The phase measurement technology is a further development of one that was described three years ago [8] but has yet to be deployed in operational equipment. Sampling is now performed using an SIS3301-80 VME sampling module from Struck Innovative Systeme GmbH. The change from 12-bit to 14-bit sampling has improved

usable resolution by 6 dB, yielding a standard deviation that never exceeds 0.04 degrees rms.

Individual cavity phase and amplitude control is obtained by the use of ferrite IQ modulators. Figure 4 is a CAD representation of the IQ modulator as proposed by AFT Microwave GmbH. The IQ modulator incorporates a magic tee with a ferrite tuner on each of the A and B legs, with a quarter wavelength difference in the total (sum of forward and reflected) path length between the two legs. If the two tuner coils are operated synchronously (with both coil currents moving in the same absolute direction), amplitude is held constant and phase is controlled. When a differential signal is applied to the tuner coils, power is reflected back toward the source, producing attenuation.
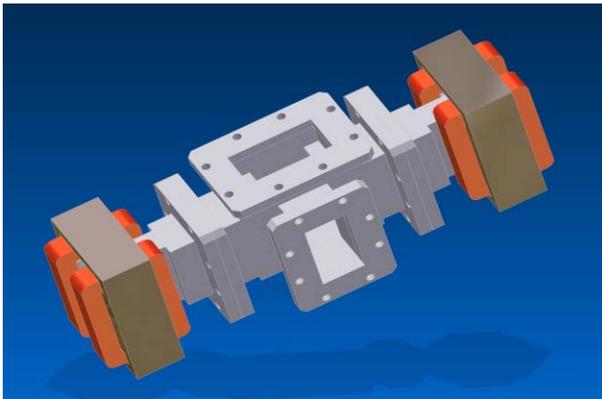
Figure 4: IQ modulator.

CONCLUSION

An rf system configuration is being put in place that has been chosen to provide the performance needed to produce short X-ray pulses with minimum technical risk and reasonable cost.

ACKNOWLEDGMENTS

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