APS Storage Ring Commissioning and Early Operational Experience*

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Abstract

The Advanced Photon Source (APS) at Argonne National Laboratory (ANL) uses a 100-mA, 7-GeV positron storage ring to produce high brilliance bending magnet and insertion device x-rays for up to 70 x-ray beamlines. It is 1104 meters in circumference and has a beam lifetime designed to exceed 10 hours with 1 nTorr average ring vacuum at 100 mA. The high brilliance required by the synchrotron light users results from the storage ring's natural emittance of 8.2 nm-rad, together with the requirement that the beam be stable to a level which is less than 5% of its rms size. Real-time closed orbit feedback is employed to achieve the required stability and is discussed elsewhere in these proceedings. Installation of storage ring components was completed early this year, and we report here on the first experiences of commissioning and operation with beam.

I. INTRODUCTION

The first revolution of beam around the APS storage ring took place March 18, 1995, with rf capture demonstrated one week later on March 25. This paper will give a brief description of APS storage ring subsystems and early commissioning activities.

II. SUBSYSTEMS DESCRIPTION

Storage ring subsystems are magnets, vacuum systems, power supplies, rf systems, controls, and diagnostics [1].

Magnets

The APS storage ring magnets consist of 80 C-core dipole magnets with a field of 0.599 Tesla, 400 quadrupoles with peak gradient near 20 Tesla/meter and including three varieties with effective lengths of 0.5, 0.6, and 0.8 meters. There are 280 sextupole magnets in the ring, three chromatic and four harmonic sextupoles in each of the forty sectors. Orbit correction is facilitated via 317 combined function vertical/horizontal correction magnets. A six-pole corrector design wired so as to null the sextupole field components is used to allow clearance for the vacuum chamber photon exit slot and antechamber. Twenty skew quadrupole magnets are also included in the lattice, straddling vacuum spool pieces between girder assemblies. Thirty-eight of the correctors also straddle these thin-walled Inconel spool pieces for improved AC magnet performance which is limited by eddy currents for those correctors having the thick-walled aluminum vacuum chamber in their bore.

Each of the forty storage ring sectors is composed of five girders upon which are mounted the magnets and vacuum chambers. These girders each rest on three wedge jack supports which have two layers of visco-elastic vibration dampening material sandwiched below them.

The lattice is of the Chasman-Green type (Fig. 1), also known as the double-bend achromat. Five-meter-long zero-dispersion straight sections reserved for insertion device installation are located at 35 places around the ring, with the other five reserved for rf cavities and injection hardware.

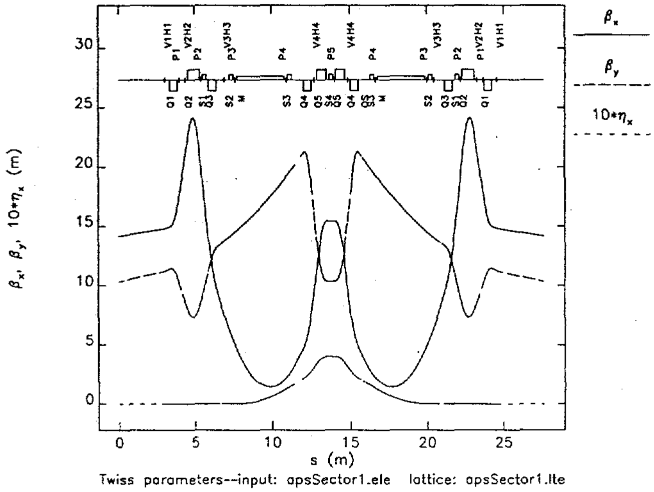

Figure 1: Advanced Photon Source Lattice

Vacuum Systems

The APS vacuum system is composed of 240 extruded aluminum chambers joined with rf-shielded bellows spool piece assemblies. Pumping occurs at the 240 photon absorber locations, one per chamber, with lumped NEG/ion pumps. Each chamber consists of a 41.7 x 84.7 mm roughly elliptical beam chamber and a photon exit slot terminated by an antechamber housing distributed NEG pumping strips. Special small gap chambers (12 or 8 mm vertical aperture) are to be installed in the long straights prior to insertion device installation.

Power Supplies

Storage ring magnets are all individually powered by pulse width modulation regulated DC-DC convertors (20-kHz choppers) with the exception of the main windings of the dipole magnets, which are bus-fed. Eighty raw DC power supplies are distributed around the ring and feed the 1414 choppers. Quadrupole and sextupole magnets have unipolar convertors, while correctors, skew quads, and dipole trim windings employ bipolar designs.

Radio Frequency Systems

Four 1-MW 352-MHz klystrons are used to drive sixteen separately tunable cavities distributed among four of the zero-dispersion straight sections. The commissioning configuration

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employs two klystrons to drive a total of 12 cavities. A target 9 MV per turn is required as overvoltage for the 5.45 MV per turn from synchrotron radiation loss at 7 GeV.

Controls and Diagnostics

The Experimental Physics and Industrial Control System (EPICS) software package is used to connect control room-based operator interface (OPI) workstations with remote input-output controller computers (IOCs). Standard EPICS tools are supplemented by in-house physics software tools used for performing a large variety of beam measurements [2]. Initial experience has been excellent.

Commissioning beam diagnostics for the storage ring include 360 AM/PM type monopulse receivers for turn-by-turn beam position monitoring, 10 fluorescent screen stations, a visible synchrotron light monitor, two sets of scraper jaws in each plane, 10 segments of long-ionization chamber style loss monitors, a pulsed and average beam current monitor, and four sets of stripline pickups and drivers for tune measurement and beam damping.

III. COMMISSIONING EXPERIENCE

The six weeks starting mid-January, 1995 were spent primarily commissioning the APS injector synchrotron for 7 GeV electron operation and completing installation of final storage ring components. Prior to this time, 4-GeV injector ramps had been used, for example during the storage ring two-sector test which took place in late October 1994. Positron operation awaits installation of a high repetition rate injection/ejection septum magnet in the positron accumulator ring. The first 7-GeV transfer of beam from the injector synchrotron to the storage ring occurred the morning of February 21, 1995 when beam was transported through the high energy transport line and through two sectors of the storage ring.

The March commissioning run was used for final checkout with beam of the large number of convertor power supplies. Response function measurements using correctors together with the beam position monitors allowed the localization of quadrupole strength errors attributed to malfunctioning power supplies. Although individual power supplies had all undergone pre-installation burn-in and checkout, operation of large numbers coincidentally using the EPICS interface required a significant effort.

First turn in the storage ring at 7 GeV occurred the morning of March 18, 1995, coincident with checkout completion for the 400 quadrupole DC-DC convertors. The next week was spent completing checkout on the sextupoles, which immediately gave up to 40 turns without rf. Strong focusing in this machine inevitably results in a large tune slew per turn if the chromaticity is not corrected.

It was decided to attempt stored beam at 4.5 GeV using a single rf source to simplify phasing This decision was fortuitous, resulting in the first rf capture on March 25, with first extracted x-rays from beamline 1-BM the next morning, March 26. These activities provided proof of principle for storage ring operation, giving confidence in the magnet survey and lattice. First stored beam at 7 GeV occurred after a 10-day shutdown the morning of April 16, now using two rf klystrons. Beam lifetime now exceeds three hours with approximately 1.E-8 Torr average ring vacuum. Vacuum bakeout work is not yet complete and will be finalized this summer.

IV. MACHINE STUDIES RESULTS

Preliminary first-turn orbit correction was performed by adjusting one corrector per sector in such a way as to minimize the mean absolute value for downstream beam position monitor readings. The same algorithm was applied to the closed orbit without rf resulting in an rms orbit relative to the beam position monitor (BPM) zero of 3 to 4 mm. BPM offsets relative to magnetic centers of quads appear to be less than about 1 mm rms, and are still under investigation.

The beam position monitors for the APS storage ring have single turn capability and employ amplitude to phase conversion (AM/PM) monopulse receivers. These have been invaluable to the commissioning efforts, for example during the process of commissioning the 400 quadrupole power supplies. Shown in Fig. 2 is the first turn vertical BPM response resulting from a Sector 2 vertical corrector change. This corrector is located just downstream from the injection point. Note the change in amplitude beginning near Sector 28. This effect was traced to a malfunctioning quadrupole power supply in that sector which was not supplying the required current. This type of problem would be extremely difficult to diagnose with beam without the first-turn capability.

An additional capability of the BPMs are the first-in, first-out (FIFO) beam history modules. Using these, for example, an FFT of the first thousand turns of horizontal beam motion after injection results in a measurement of horizontal tune resulting from the injection transient betatron oscillation. In Fig. 3 the plot is presented in fractional tune units along the x-axis and arbitrary units vertically. The structure near 0.5 is an artifact of the plus/minus shot-to-shot toggling of the BPMs

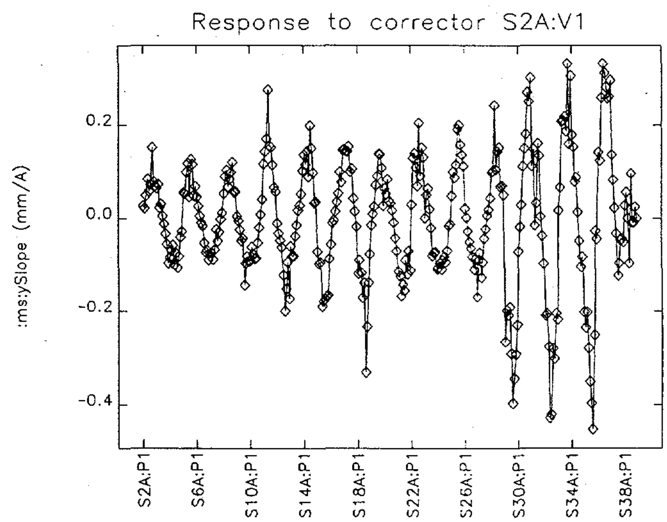

Figure 2: First turn beam position monitor response function.

required for electronic offset compensation. Note the clear signal near $v_x = 0.23$ (0.77).

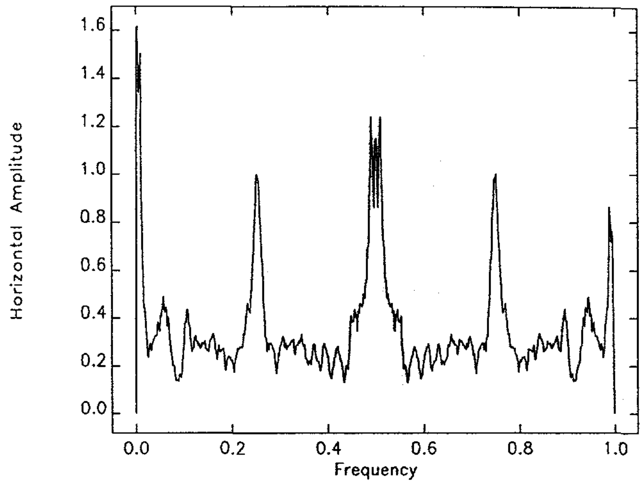

Figure 3: FFT of first 1,048 turns of horizontal beam motion.

Lattice modeling has been confirmed both by tune measurements and closed orbit corrector response function measurements. Shown in Fig. 4 is a comparison between measured and theoretical vertical response functions. In addition to the beam position monitor beam history modules, stripline pickups in conjunction with a vector signal analyzer are used for tune measurement. The beam is excited both with the amplified analyzer source (vertical) and with an injection bumper magnet powered at a low level (horizontal). Spectra similar to Fig. 3 result, and peak detection software is used to automate tune and chromaticity measurement. Figure 5 shows the first chromaticity measurement for the APS storage ring using predicted zero chromaticity values for the sextupoles. Natural chromaticities are $d\nu / d\delta = -58$ and -14 for the horizontal and vertical planes, respectively. The top trace is the vertical tune and the bottom is horizontal.

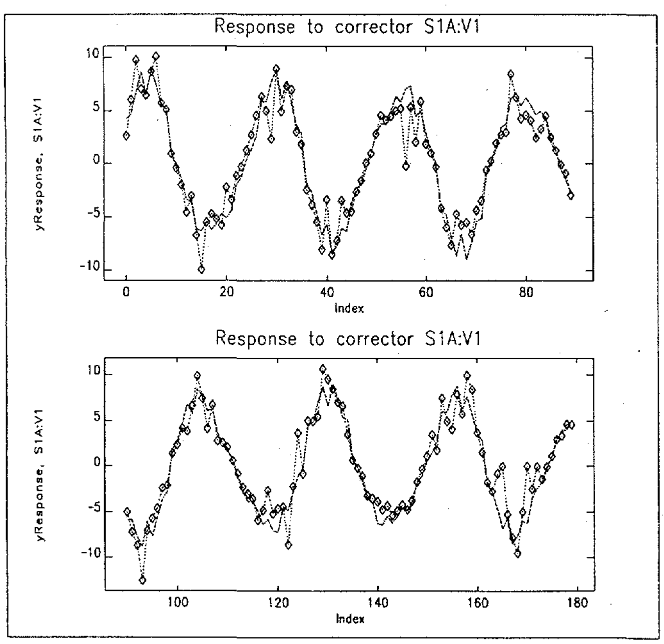

Figure 4: Stored beam vertical response function (0.1 mA).

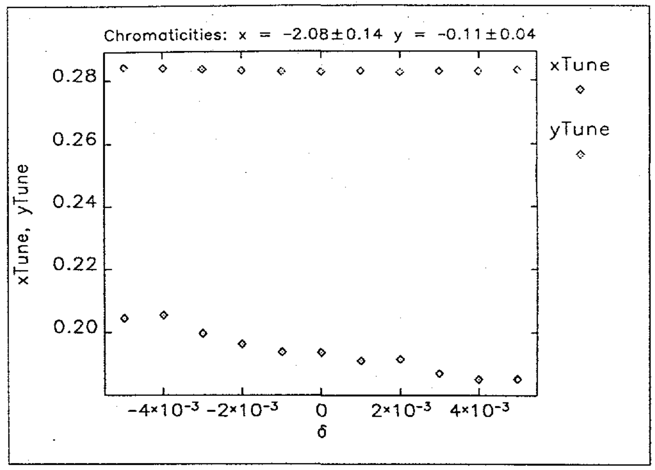

Figure 5: APS storage ring chromaticity measurement.

V. CONCLUSIONS

Commissioning of the APS storage ring is nearing completion. Closed orbit correction algorithms are being implemented at the time of this writing with significant success already. Items remaining are multibunch stacking, high intensity operation, and finally, installation and commissioning of insertion devices together with associated real-time digital closed orbit global and local feedback and beam missteering interlocks.

VI. ACKNOWLEDGEMENTS

This paper would not have been possible without the dedicated efforts of the entire APS Accelerator Systems Division (ASD) over the past two years. Michael Borland and Louis Emery performed the lion's share of data acquisition and machine modeling of which I am primarily the reporter. Steve Milton, John Carwardine, and Nick Sereno have served tirelessly commissioning and operating the injector synchrotron during this commissioning period. Ken Evans generated some extremely useful graphics tools the end results of which are shown here. The ASD Operations Group has been of enormous value providing reliable beam from the linac and positron accumulator ring.

VII. REFERENCES

[1] 7-GeV Advanced Photon Source Conceptual Design Report, ANL-87-15, April 1987.

[2] L. Emery, "Commissioning Software Tools at the Advanced Photon Source," these proceedings.