Commissioning of the Argonne Positron Accumulator Ring*

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Abstract

The Advanced Photon Source (APS) injector consists of a 250-MeV electron linac, a 450-MeV positron linac, a 450-MeV positron accumulator ring (PAR), and a 7-GeV synchrotron. The purpose of the PAR is to accumulate and damp positrons from the 60-Hz linac during each cycle of the 2-Hz synchrotron, thus increasing the fill rate for the main ring. This paper discusses the rapid progress of PAR commissioning. Less than a year was required from first acceptance of beam to transfer of PAR operations to the APS Operations Group. PAR has been well characterized and already meets most of its design specifications. An accurate model has been developed for linear and chromatic properties. Hardware improvements are planned to allow specifications to be fully met.

I. INTRODUCTION

The APS is a 7-GeV positron storage ring that recently delivered "first light" to users. Positron are desirable to eliminate the ion trapping. Because of the inefficiency of positron creation, filling the APS would be slow with the 2-Hz synchrotron. By accumulating charge as the synchrotron ramps and damping the transverse and longitudinal emittances, the PAR increases the fill rate. The principle challenge of PAR was to obtain fast transverse damping and a $\pm 1\%$ energy acceptance, both needed for efficient 60-Hz positron capture.

The PAR design operational cycle lasts 0.5 s. For the first 23/60 s, linac pulses are accepted at a 60-Hz rate. These 0.25-pC, 30-ns FWHM pulses are captured in a first-harmonic, 9.77-MHz rf system. At 1/60 s after injection of the last pulse, a twelfth-harmonic rf system is activated to compress the bunch length from 1-ns to 0.3-ns rms. The bunch is sent to the synchrotron 1/60 s prior to the start of the next cycle.

PAR commissioning began March 7, 1994 using a 177-MeV electron beam from the APS linac, which itself was still being commissioned. Beam was stored at 250 MeV on April 17, 1994, after approximately 35 hours of beam time, on the first shift that had rf available. Due to continuing difficulties with the linac, commissioning has to date used only electrons. Detailed information on the PAR design, a hardware overview, and additional commissioning information are available in the references [1,2]. This paper concentrates on development of the machine model, recent longitudinal dynamics results, septum leakage fields, and upgrade plans.

II. MODEL DEVELOPMENT AND TESTING

When beam was first stored in PAR at 250 MeV, the measured tunes were different from the design values. This was not unexpected, since the ring has 1-m bending radius dipole mag-

nets, with excitation-dependent edge-angles and soft-edge effects [3].

Adjusting the edge-angle largely reconciled measurements and model. Using the adjusted model, a lattice to restore the tunes was created. This worked well, and the method was repeated as the available linac energy increased.

When 450-MeV beam was achieved, the tunes disagreed with the model if the nominal dipole parameters were used. However, adjustment of these parameters was sufficient to produce an accurate model of the linear properties, i.e., of the response matrices and dispersion. The validity of the model in the region around the working point is also good. No other parameter adjustments (e.g., quadrupole strength errors) were found that could explain the measured data as simply.

Figure 1 shows measured and predicted tunes for several lattices. Lattice 1 is the fit point, while the others are test lattices that have (largely) only one of the tunes changed. The model was used to adjust the quadrupoles for each test lattice to give the desired tunes, while limiting changes in the dispersion. Agreement is good except for the horizontal tune for lattice 3; the reason for the problem with lattice 3 is unknown.
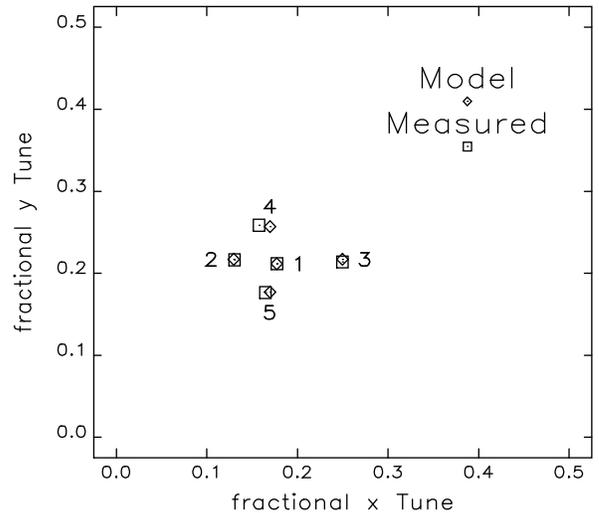

Figure 1: Tune Data and Predictions

Figure 2 shows representative vertical response-matrix data for lattices 1, 3, and 5, which have different vertical tunes. Similar agreement is found for the horizontal plane. Figure 3 shows the measured and model horizontal dispersion. The vertical dispersion is zero to within measurement accuracy. Figure 4 shows the rms normalized deviation of the horizontal (x) and vertical (y) response, and horizontal dispersion. Normalization is to the maximum value of each quantity. The deviations are generally small but statistically significant.

In comparison to the linear model, the chromatic model is relatively simple. The most difficult-to-know parameter is the sextupole, $K_2 = -d^2/dx^2(B_y/(B\rho))$, in the dipole. This is
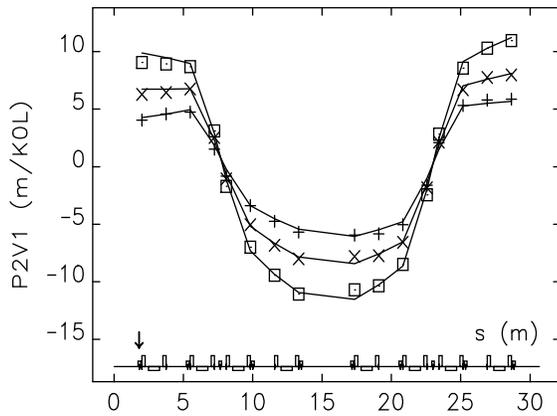
Figure 2: Sample Response Data and Predictions

known to vary between the ends and the center of the magnet. Further, fitting polynomials to the measured field to extract this small term is ambiguous. Turning off all sextupoles gives an easily measured chromaticity for both planes that can be fit reasonably well (see below) by adjusting K_2 . Table 1 summarizes the parameters of the model, along with nominal values from magnetic measurements. The soft-edge parameter K is defined in [3]. Table 2 summarizes the tunes and chromaticities for the nominal and model parameters along with measurements.

Table 1: Nominal and Model Parameters

Parameter	Nominal	Model
E (degrees)	25.50	25.67
K	0.424	0.399
$K_2 \left(m^{-3} \right)$	0.14	0.50

Table 2: Tunes and Chromaticities

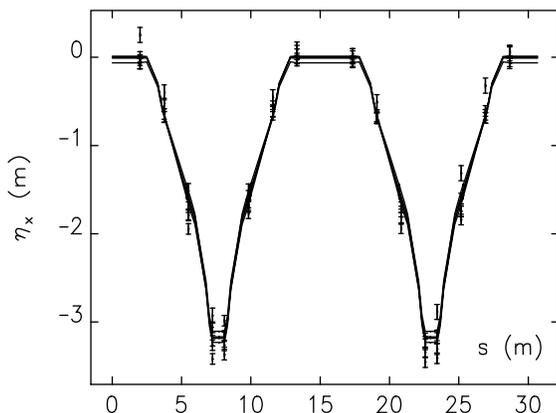| Parameter	Nominal	Model	Measured
x tune	2.191	2.177	2.177
y tune	1.140	1.211	1.210
x chrom.	-0.42	-0.89	-0.70±0.05
y chrom.	-6.15	-3.18	-3.08±0.05

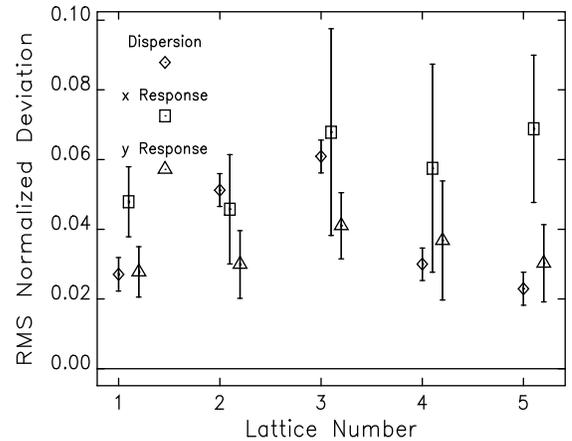Figure 3: Dispersion Data and Predictions

Figure 4: Summary of Model Agreement with Measurements

III. LONGITUDINAL DYNAMICS

Proper functioning of PAR depends on proper functioning of the bunch-compressing harmonic cavity system. During accumulation, the cavity is detuned 150 kHz and deQed five-fold by ferrite loading. This limits beam excitation of the cavity, preventing minibucket formation. Some excitation is desirable to give Robinson damping, which motivated the extent of loading. Early commissioning encountered a longitudinal instability due to deliberately excessive ferrite loading.

Presently, longitudinal instability occurs above about 5-nC stored charge—below the 6-nC goal but above the 3.6 nC specified in the Conceptual Design Report (CDR) [4]. The cause is unidentified; it may be a cavity higher-order mode (HOM) or a feedback problem. Figures 5 and 6 show the bunch length as a function of time (measured with a fast photodiode on a synchrotron light port) during compression for 4.8-nC and 5.9-nC stored charge, respectively. For the latter, the compressed beam is unstable. The time access calibration for these figures is uncertain and hence is not given.

IV. SEPTUM LEAKAGE FIELD

The original PAR septum was a transformer design with a 2-mm copper-iron sandwich for the septum wall. This design had excessive leakage fields. A new direct-drive design is now in use [5]. To measure leakage fields with beam, a single BPM was read turn-by-turn as the septum was pulsed. Since the septum pulse is slow compared to betatron oscillations, the closed orbit follows the leakage field adiabatically. The model was used to compute the leakage field required to produce the observed closed orbit change. By repeating the experiment with the initial closed orbit at different distances from the septum wall, the leakage field vs. distance from the septum wall can be measured. Figure 7 shows three traces of percent leakage field relative to the peak septum field for different initial closed orbits. The traces are labeled by the closest approach the closed orbit makes to the septum. The design places the septum wall 20 mm from the closed orbit. One sees that at 9.7 mm from the septum, the peak leakage field is 0.5%, or 4 G. This is a fourfold improvement over the transformer septum,

and meets requirements. The figure shows the prompt and delayed terms of the leakage field; the dominance of the latter indicates that field is penetrating the septum wall rather than coming from some other source.

V.   STATUS AND IMPROVEMENT PLANS

PAR performance relative to the design is good in spite of a few problems. The ring has operated reliably and routinely at the 450-MeV design energy. The damping rate agrees with expectations, and the energy acceptance is better than ±0.8 %. Operation of PAR by non-physicist operators began after less than one year of commissioning. Capture efficiency for electrons with 20-Hz injection is essentially 100%. A single test of 30-Hz injection has been performed, with no loss in efficiency relative to 10 or 20 Hz. Still, several systems require upgrade before PAR can perform complete as designed.

The fundamental rf system delivers 27 kV compared to the minimum 30 kV for "100%" positron capture. The harmonic system delivers 17 kV compared to 30 kV required for the design 0.28-ns rms bunch length. Replacement of solid-state amplifiers with tube amplifiers will provide more power, but improved fundamental-cavity cooling is required.

The septum will shortly be replaced with a direct-drive magnet capable of 60-Hz operation. The present magnet lacks water cooling and is limited to 3 Hz at 400 MeV.

Continued investigation of the rf feedback systems and HOMs will be required to raise the longitudinal instability threshold above 6nC. The energy acceptance appears to be lower than desired, for unknown reasons (it is apparently not rf-related). Resolution of such issues is not urgent in the context of the beginning of commissioning of the APS itself, as PAR easily delivers over the CDR-specified 3.6 nC/cycle.

VI.   ACKNOWLEDGMENTS

Design, construction, and commissioning of the PAR was the work of many individuals, whom I am pleased to acknowledge here: C. E. Anderson, J. A. Boggs, J. F. Bridges, J. Curarine, E. A. Crosbie, R. Dame, DANFYSIK Corporation, R. J. Dortwegt, L. Emery, K. Evans, R. Ferry, J. N. Galayda, K. Halbach, R. Holsinger, J. M. Jagger, E. Kahana, Y. W. Kang, R. T. Kmak, M. J. Knott, R. L. Kustom, F. R. Lenkszus, F. Lopez, A. Lumpkin, W. P. McDowell, D. G. McGhee, F. E. Mills, S. Milton, H. J. Moe, P. L. Morton, G. J. Nawrocki, J. R. Noonan, D. R. Paterson, C. Saunders, N. S. Sereno, S. Sheynin, W. Sellyey, T. L. Smith, J. Stepp, L. C. Teng, L. R. Turner, J. Wang, and X. Wang.

VII.   REFERENCES

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[2]   M. Borland, "Commissioning of the Positron Accumulator Ring for the Advanced Photon Source," to be published in *Nuclear Instruments and Methods*.

[3]   K. L. Brown, "A First- and Second-Order Matrix Theory for the Design of Beam Transport Systems and Charged Particle Spectrometers," SLAC Report-75, June 1982.

[4]   "Annex to 7-GeV Advance Photon Source Conceptual Design Report," ANL-87-15 Annex, May 1988.

[5]   S. Sheynin, et. al., "The APS Direct-Drive Pulsed Septum Magnets," these proceedings.
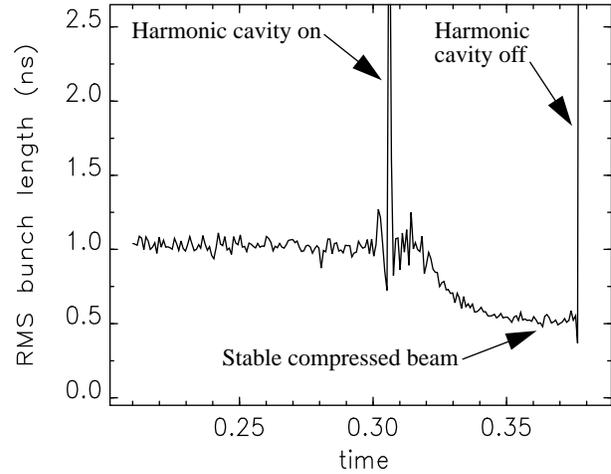
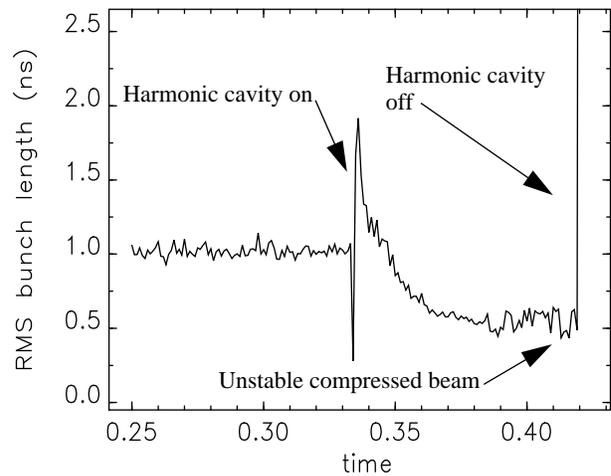Figure 5: Bunch Length vs Time for 4.8nC Stored Charge
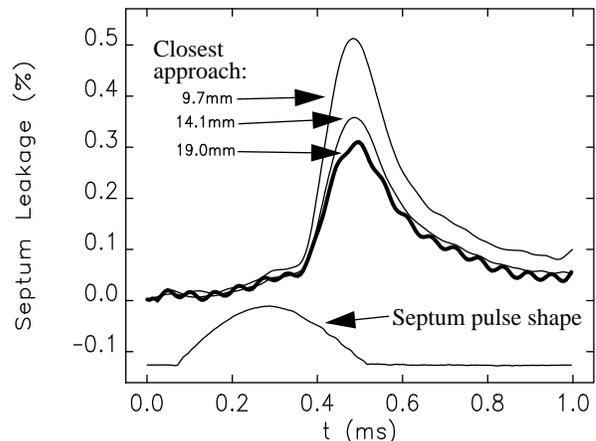

Figure 6: Bunch Length vs Time for 5.9nC Stored Charge

Figure 7: Septum Leakage Field Measurements