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Construction and Commissioning of the Positron Accumulator Ring for the APS

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Abstract

The injector for the Advanced Photon Source (APS) incorporates a 450-MeV positron accumulator ring (PAR) to accumulate and damp positrons from the 60Hz linac during each cycle of the 2-Hz synchrotron. An overview of PAR hardware is presented. Commissioning of the PAR is well underway using electrons. Studies have produced a modified lattice model using three free parameters that agrees well with measurements. Principle problems are high leakage fields from the septum and ion trapping.

1 Introduction

The APS[1], now nearing completion at Argonne National Laboratory, is a 7-GeV positron storage ring served by a full-energy injector consisting of a 2-Hz synchrotron, a 450-MeV positron accumulator ring[2, 3], a 450-MeV positron linac, and a 200-MeV electron linac[4].

Use of positrons negates ion-trapping problems, but it complicates the task of the injector. Positron production is inefficient and gives a large emittance and momentum spread. Like DESY's PIA ring[5], the PAR's purpose is to accumulate and damp many positron macro-pulses for delivery to the synchrotron.

The PAR operating cycle lasts 500 ms and will eventually use a 60-Hz injection rate. The cycle begins with accumulation of 24, 0.25-pC, 30-ns-long positron pulses using a 9.8-MHz 1^{st}-harmonic rf system. At 1/60 s after the last pulse, a 12^{th}-harmonic rf system is activated, reducing the equilibrium RMS bunch length from 0.9ns to 0.3ns. Extraction occurs after waiting 5/60 s for damping. The 12^{th}-harmonic rf is deactivated and 1/60 s later, the next cycle begins.

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2 PAR Construction

Figure 1 shows a simplified plan view of the 30.67-m-circumference ring. The lattice has reflective symmetry about the horizontal and vertical lines through the center. The following is a hardware-oriented overview. Design considerations and parameters are in the references[2, 3].

PAR contains eight conventional 1.5-T, solid-core, flat-field, 45° dipole magnets with a 1.02-m bending radius, 45-mm gap, and no gradient. Unlike PIA, damping partition adjustment was achieved with 25.5° edge angles rather than a gradient, thus simplifying design, fabrication, and measurement.

Four families of four ganged, conventional, solid-core quadrupole magnets provide focusing. Both the quadrupole and sextupole designs have large bore radii (66mm and 65 mm, respectively) relative to the core length (180mm and 170mm, respectively). Magnetic measurements showed a 0.9% strength reduction due to the proximity of a dipole or sextupole core. This is incorporated in the machine model.

Ten conventional, solid-core sextupole magnets provide both steering and chromatic correction, using three sets of windings for each magnet. Use of a six-pole rather than a twelve-pole magnet gave a higher quality sextupole field, but a lower quality dipole field—a favorable trade-off for the dynamic aperture.

A single transformer septum magnet[6] with a 2-mm wall is used for injection and extraction. The 0.4-m-long, 0.75-T magnet is pulsed with a 1500-Hz half sine-wave. Leakage field is $\sim 2\%$ of the main field 5 mm from the septum wall. The lack of cooling prevents pulsing faster than 10 Hz. After running 4-6 hours, a "fatigue" condition develops that makes accumulation difficult, possibly due to a temperature-related change in the septum wall's magnetic properties. The magnet will be replaced by a water-cooled, direct-drive design[6] promising much lower leakage fields and 60-Hz operation.

PAR employs three delay-line kickers[7] with 10%-90% rise and fall times of $\sim 90 - 120$ns, 0.35m effective length, and 170 G-m maximum strength. The injection kickers were optimized for fall time, the extraction kicker for rise time. Ceramic chambers[8] are used, with a resistive interior-surface coating.

The 1^{st}-harmonic rf system is use to capture beam and restore energy lost as synchrotron radiation. The gap-loaded[9], ferrite-tuned cavity presently provides up to 23 kV gap voltage. This is less than the 29 kV needed for efficient positron capture due to cavity heating and limited tuner range. A 15-20 kV 12^{th}-harmonic system provides threefold bunch compression. The idling cavity acts as a longitudinal damper by virtue of incomplete detuning. Both cavities are at atmospheric pressure, being fabricated of sheet metal "clam shells" that are clamped around ceramic gaps in the beam tube.

Design pressure in PAR is 1×10^{-7}T with a 60-mA stored beam, giving an estimated lifetime of 1/2 hour to facilitate machine studies. Presently, because of two leaking kicker ceramic chambers, the pressure is about 2×10^{-6}, giving a beam lifetime of about 60 s at 400 MeV, much longer than the 0.5-s cycle time.

Diagnostics[10] include 16 stripline beam position monitors (BPMs), six fluorescent screens, dual fast/integrating current transformers, a tune measurement system, two synchrotron light ports, a four-segment gas-filled beam-loss ion chamber, and independent vertical and horizontal window-frame scrapers.

3 Commissioning Results

Positrons being unavailable, PAR commissioning began and continued with electrons, starting at 150 MeV and moving higher as linac commissioning progressed. Six turns were achieved at 150 MeV without kickers. Use of kickers gave approximately 14000 turns at 250 MeV. Once rf was available, beam was stored at 250 MeV. In all, approximately 35 hours of beam time was used. Presently, 10-Hz accumulation with 90-100% efficiency at 400 MeV is routine. Circulating current of 140 mA—over twice the 60-mA design goal—has been stored at 450 MeV.

Since initial stored beam at 250 MeV was very weak, the tune measurement system did not work. Instead, a digital scope was used to FFT the signal from a diagonally-masked photomultiplier tube on a synchrotron light port, giving a fractional vertical tune of $\Delta\nu_y = 0.34$. The design horizontal and vertical tunes are $\nu_x = 2.170$ and $\nu_y = 1.217$, respectively.

Knowing that the dipole edge-angle and soft-edge integral[11] depend on excitation level, an attempt was made to deduce these values from the measured tune. A reasonable edge-angle change (0.8°) matched the measured vertical tune. Quadrupole strengths expected to restore the lattice to the design were computed based on this change. These strengths permitted more beam to be stored, allowing measurement of both tunes, giving $\Delta\nu_x = 0.164$ and $\Delta\nu_y = 0.208$.

This procedure was repeated as the available beam energy increased. For the 450-MeV model a two-parameter model was used, since high-resolution measurement of both tunes was by then routine. In particular, an edge-angle of 25.67° (compared to 25.5° in the design) and a soft-edge integral of 0.399 (compared to 0.424 in the design) gave a match to both measured tunes.

To test this model, the tunes, dispersion, and closed-orbit response matrices of a set of lattices around the operating point were characterized. These lattices differed from the operating lattice by having one of the tunes changed, with the dispersion function kept as unchanged as possible. Standardization of the magnets between lattices was important. A single ramp cycle between lattices gave systematic deviations from the model, while two cycles did not.

Figure 2 shows the measured and predicted tunes for the five lattices. Figure 3 shows the normalized RMS deviations of the dispersion and response matrices for the five lattices. The values are normalized to the relevant maximum value. The differences from the model are generally small, but statistically significant.

Chromaticities were measured with and without sextupoles for the operating lattice only. Since the most significant relevant unknown is the effect of the small-radius dipole, the body sextupole term ($K_2 = \partial_x^2 B_y/(B\rho)$) was used as the model's free parameter. The sextupole term actually varies as the beam travels from the end to the center of the magnet, whereas the design model used the value from computer simulations that ignored such effects, giving $K_2 = 0.141/\mathrm{m}^3$. $K_2 = 0.491/\mathrm{m}^3$ was found to reproduce the measured chromaticities to 1 sigma. Measurement of the chromaticity with sextupoles on proved difficult, since unrelated tune drifts masked the small change due to chromaticity. Cleaner measurements at 400 MeV gave chromaticity changes due to sextupoles within 2 sigma of prediction.

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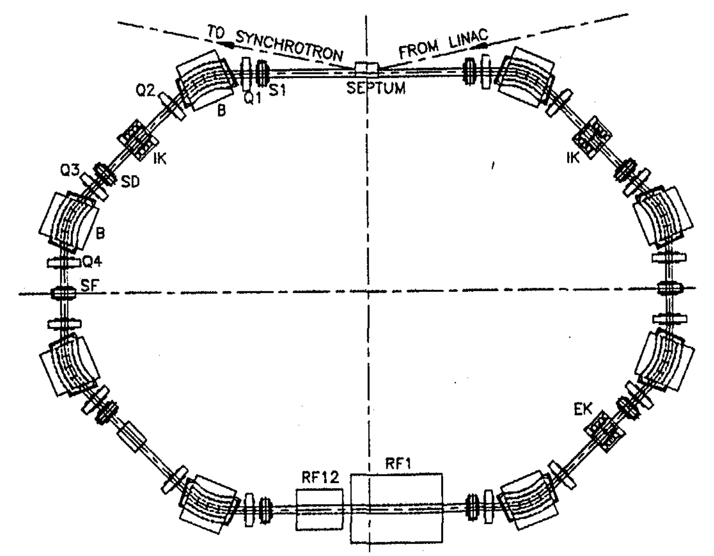
Figure 1: Simplified PAR plan view

Figure 2: Measured and model tunes for the five lattices.

Figure 3: Deviation of measured dispersion and closed-orbit response matrices from the model for the five lattices.

Fig 1


TO SYNCHROTRON
FROM LINAC
SEPTUM
Q2
B
Q1
S1
IK
Q3
SD
B
Q4
SF
IK
EK
RF12
RF1

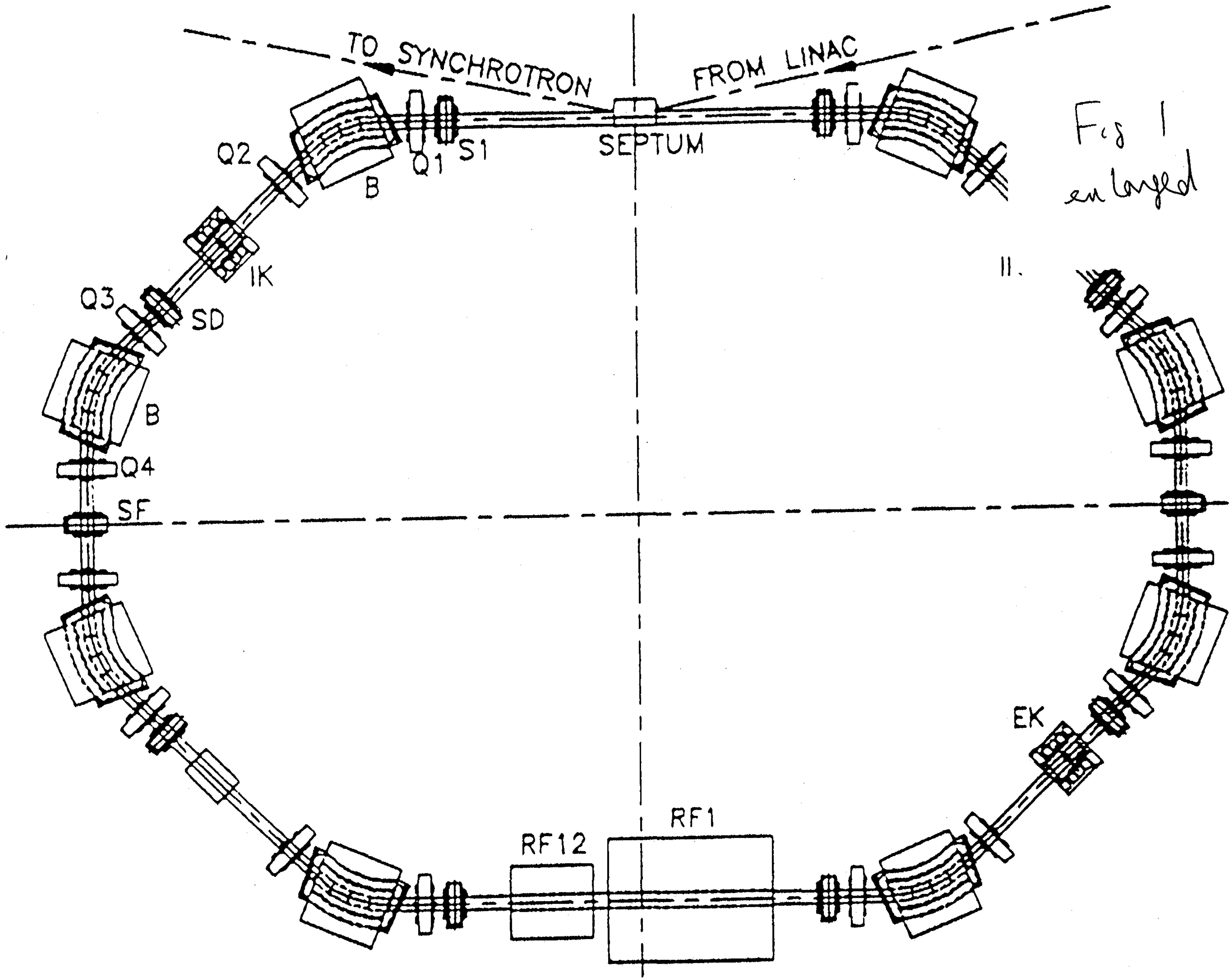
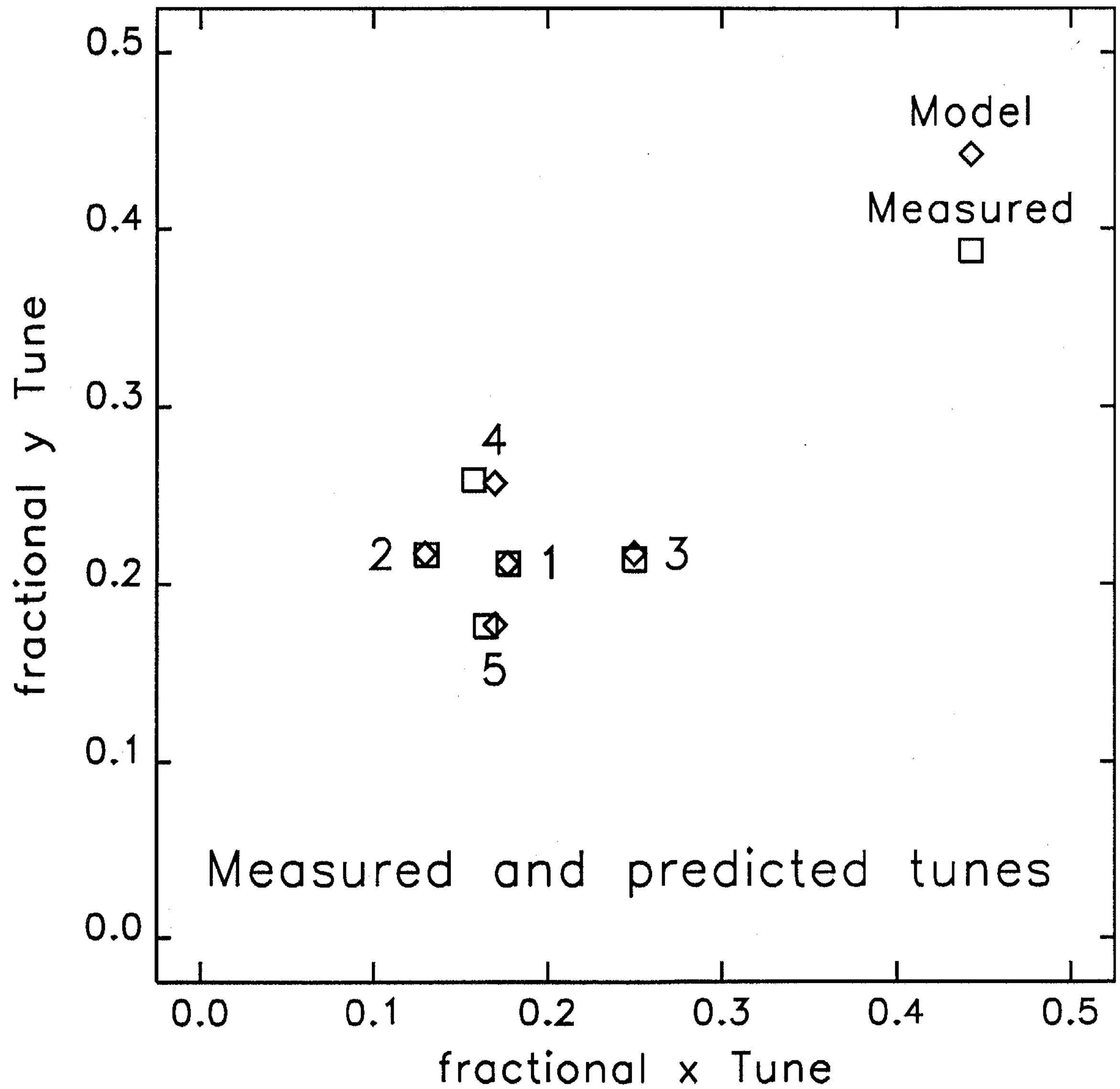


Fig 1 enlarged

Fig 2


Model
Measured
4
2
1
3
5
Measured and predicted tunes
fractional y Tune
fractional x Tune
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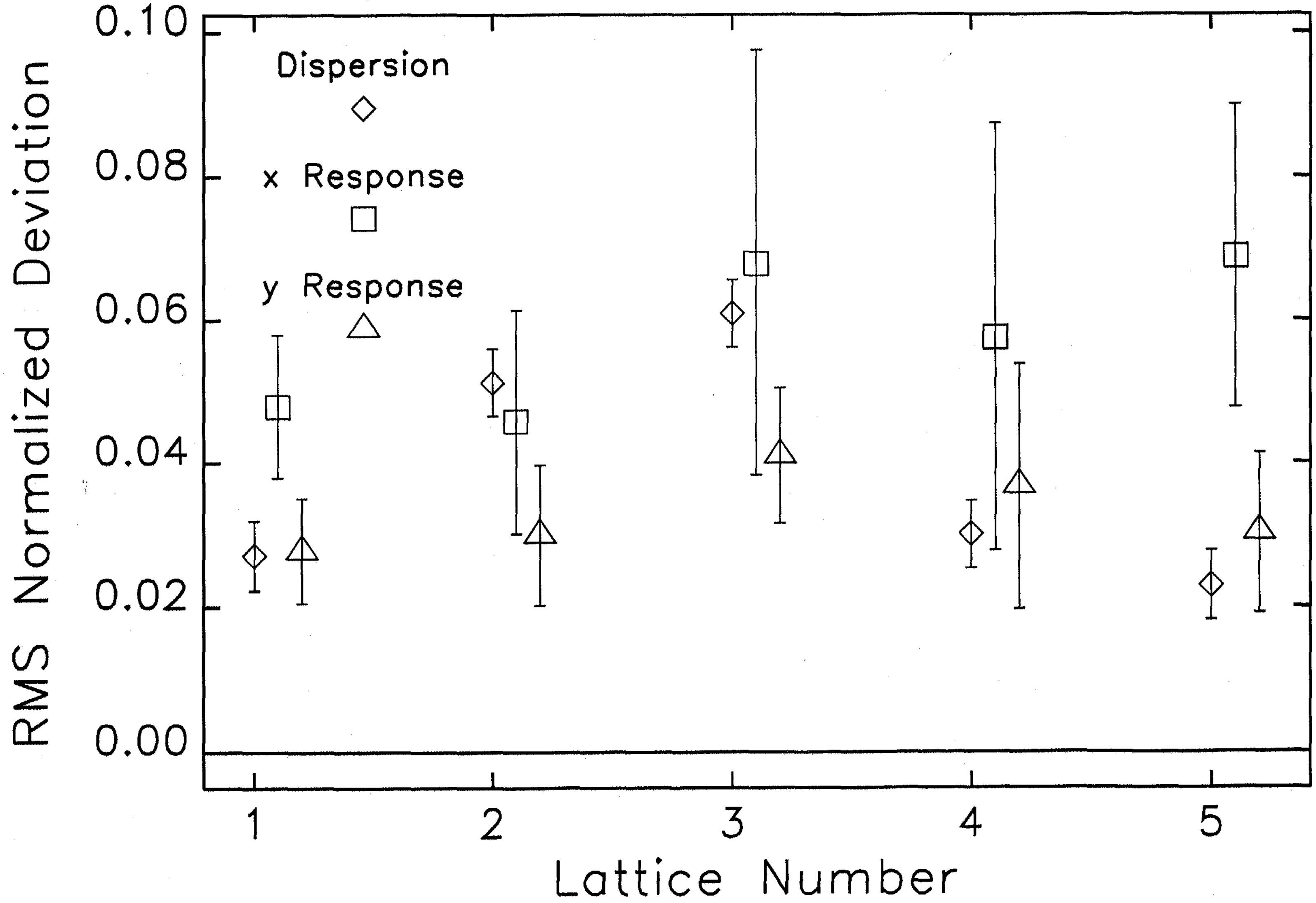
0.1
0.2
0.3
0.4
0.5



Dispersion
x Response
y Response
0.10
0.08
0.06
0.04
0.02
0.00
1
2
3
4
5
RMS Normalized Deviation
Lattice Number