SPEAR3 NONLINEAR DYNAMICS MEASUREMENTS

J. Safranek, X. Huang, J. Corbett, J. Sebek, A. Terebilo, SSRL/SLAC, Menlo Park, CA, U.S.A.

Abstract

We present nonlinear dynamics measurements and tracking for the SPEAR3 storage ring. SPEAR3 does not have a vertical pinger magnet, so we have developed a method of measuring (x, y) frequency maps by exciting vertical oscillations using a strip line driven with a swept frequency. When the vertical oscillations reach the desired amplitude, the drive is cut, and an injection kicker excites horizontal oscillations. The subsequent free horizontal and vertical betatron oscillations are digitized turn-by-turn. We have used measured and tracked frequency maps in (x, y) and (x, energy) to characterize and optimize the dynamic aperture, injection and lifetime of the SPEAR3 low emittance optics.

INTRODUCTION

The accelerator physics group at SSRL works to maximize the performance of SPEAR3 as a synchrotron light source. As part of this work, we investigate and implement optics modifications to improve the photon brightness; we simulate the effects of new proposed insertion devices on SPEAR3 beam dynamics; and we work to maximize the dynamic aperture and lifetime. All these tasks require a good understanding of both the linear and nonlinear optics of the storage ring.

Our understanding of the linear optics is quite good. Our calibration of the SPEAR3 nonlinear optics, however, needs improvement, so we can accurately predict machine performance when adding new insertion devices or modifying the linear optics.

Tune map measurements at other light sources have been shown to be a useful tool for experimental calibration of nonlinear optics [1, 2]. These previous measurements have relied on pulsed "pinger" magnets that kick the beam to large transverse oscillation amplitude in both the horizontal and vertical planes. At SPEAR, and at many other light sources, we do not have pinger magnets installed. We have developed an alternative method to measure frequency maps using a strip line driver and horizontal injection kicker.

EXPERIMENTAL SETUP

Figure 1 shows the experimental setup we arrived at after trying various configurations. We amplify the output of a waveform generator to drive a stripline and excite vertical betatron oscillations. We sweep the drive frequency, starting from well below the vertical tune, and sweeping through it. SPEAR3 has positive vertical tune shift with vertical amplitude. For a ring with negative tune shift with amplitude, it would be better to start above the tune and sweep down.

As the tune is swept up, the beam naturally excites to the amplitude that corresponds to the tune vs. amplitude curve for the drive frequency. This only works if the drive amplitude is sufficiently large, and the sweep rate is not too fast. If the sweep rate is too fast, the beam drops back to small amplitude. On the other hand, it is better to have a fast sweep rate to minimize decoherence of the beam. For SPEAR3, we found that a sweep rate of 222 kHz/second strikes a working balance.

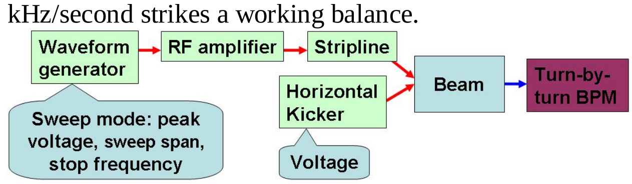

Figure 1: Experimental setup.

The stop frequency of the driver sweep determines the final vertical amplitude. When the tune driver reaches the stop frequency, the drive frequency immediately shifts back to the start frequency, well below the vertical tune, effectively cutting the drive. A single horizontal injection kicker is timed to fire at this same moment, after which the beam is left to oscillate freely in both the horizontal and vertical planes.

Figure 2 shows a measurement using single-turn Echotek [3] BPMs. The first ¾ of the top graph shows the vertical amplitude growing as the drive frequency increases. The vertical drive stops just as an injection kicker kicks the beam horizontally. The expanded view in the bottom graph shows the subsequent damping (and beam decoherence) of the free betatron oscillations. We fit a damped sinusoid to the first 128 turns (plotted in red) to get the horizontal and vertical amplitude and tunes.

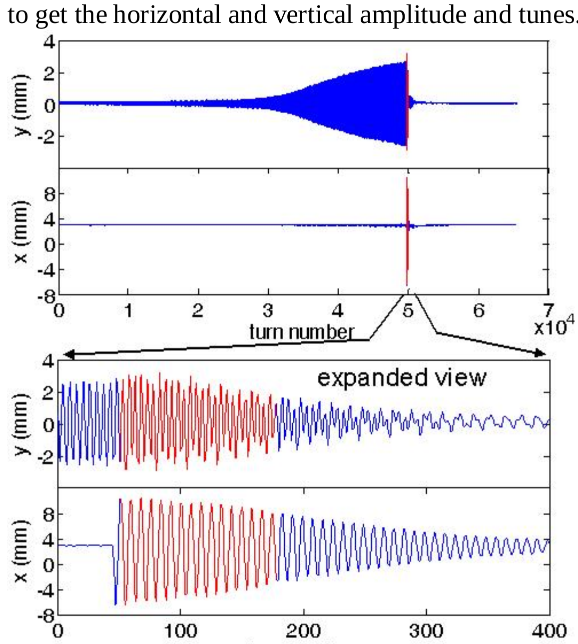

Figure 2: Driven vertical and kicked horizontal oscillations. Top: 2^{16} turns. Bottom: expanded view.

We make the measurements with 4 mA distributed over 80 consecutive RF buckets. We measure the kick amplitude as a function of injection kicker timing to ensure the 80 bunch train spans the flat top of our injection kicker pulse.

Beam Decoherence

Note that the oscillations in figure 2 damp down at a rate much faster than the synchrotron radiation damping time. This is due to decoherence of the electron bunches. Decoherence happens fastest when the oscillations are large in both horizontal and vertical, as in Fig. 2. When the horizontal kick is small, the transverse oscillations decay slowly at the synchrotron radiation damping time (~6000 turns).

At first we tried simultaneously exciting horizontal and vertical betatron oscillations with the stripline. Decoherence forced us to switch to the injection kicker for generating horizontal oscillations.

Figure 3 shows measurements of the beam decoherence when driving vertical oscillations only. The top plot shows BPM measurements of the electron beam oscillations. The bottom three plots show transverse beam profiles for a series of turns captured on our synchrotron light monitor (SLM) [4] at three different points in the ramp. The beam is close to being scraped off on the vacuum chamber at 26 msec (turn 33290). The series of single-turn images at 26 msec shows smearing in phase space. Analysis of the digitized profiles at 26 msec shows that the angular extent in (y, y') phase space of the decoherence is such that the amplitude measured by the electron BPM shows only a few percent reduction from the true amplitude. This decoherence is small enough that the beam acts like a single particle, so decoherence does not significantly compromise the measured BPM data.

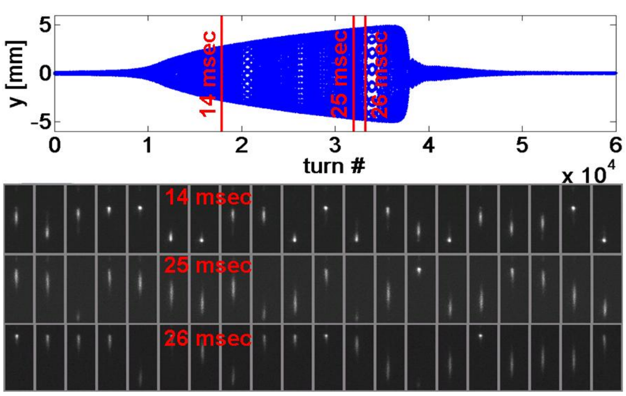

Figure 3: Top plot: BPM measurements of y_β oscillations with swept frequency drive. Bottom three pictures: series of single-turn beam profiles at three points of top plot.

Injection Kicker Reproducibility

Monitoring the injection kicker amplitude shows that it is quite stable. The timing of the vertical tune drive sweep and the injection kicker is synchronized with the 60 Hz line voltage to avoid variations in the beam response from power supply ripple.

The size of the horizontal kick, however, does vary due to variations in the phase of the vertical betatron oscillations when the kicker is fired. The injection kickers in SPEAR3 are air-core stripline kickers [5], so the kick strength varies with transverse position. For large vertical y_β oscillations, the horizontal kick varies by as much as 3.5%, depending on the phase of y_β when the kicker fires. We can determine the actual kick size from the BPM data, so the variation in horizontal kick can be calibrated out.

MEASUREMENTS

Figure 4 compares measured and model tune maps with all insertion device gaps opened. The low amplitude tunes are [14.106, 6.177] at the lower left side of the plot. The ratio $(d\nu_y/dx^2)/(d\nu_x/dx^2)$ is similar to the ratio $(d\nu_y/dy^2)/(d\nu_x/dy^2)$, so the SPEAR3 tune map makes a relatively narrow strip in tune space. The color scheme has constant color for fixed horizontal kick. For example, dark blue marks trace a curve for increasing vertical amplitude at the smallest horizontal kicker setting.

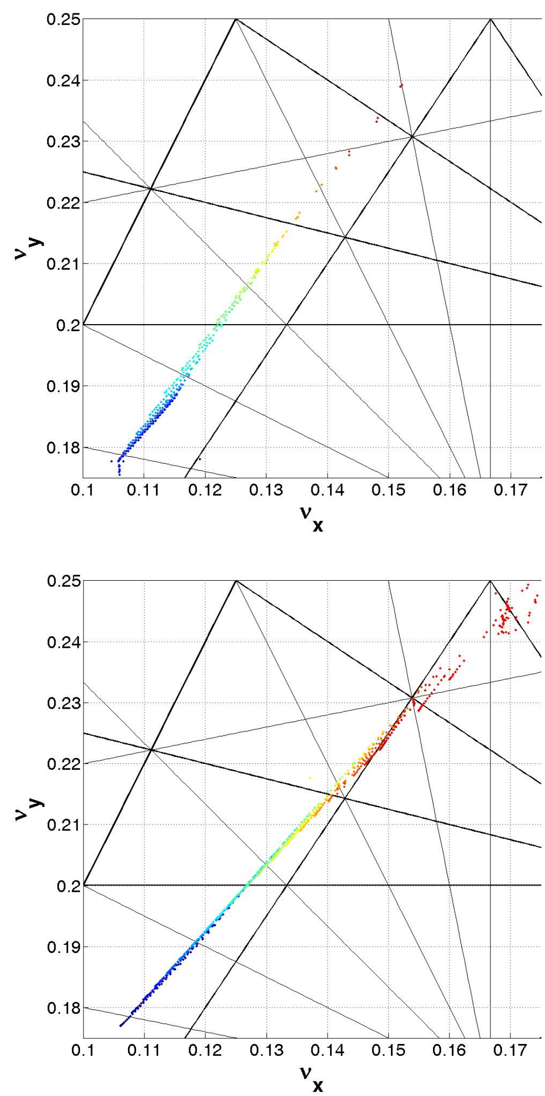

Figure 4: Measured (top) and model (bottom) tune maps.

Table 1 compares the measured and model tune shifts with amplitude. The values are calculated from the data in Fig. 4.

Table 1: Tune Shifts with Amplitude

	Measured	Model
$d\nu_x/d\varepsilon_x$ [1/m]	1590	1803
$d\nu_x/d\varepsilon_y$ [1/m]	2460	2145
$d\nu_y/d\varepsilon_x$ [1/m]	2200	2058
$d\nu_y/d\varepsilon_y$ [1/m]	2740	2131

The model tune map slopes up at a slightly lower angle than the measured map. The slope is determined by the ratios $(d\nu_y/d\varepsilon_{x,y})/(d\nu_x/d\varepsilon_{x,y})$. Due to this difference, the measured tune map avoids the resonance intersection at tunes (0.154, 0.231), while the model tune map hits it. The tune working point is good for the real ring, but problematic in the model.

We plan to work to improve our model to give better agreement with measurements. We will investigate improving the model of our magnet end fields, as in reference [2].

Figure 5 shows a tune map in (x, δ). In measuring this data, we fired an injection kicker to kick horizontally to varying amplitudes. We did this for different RF frequencies, so the off-energy (δ) variation does not include synchrotron oscillations.

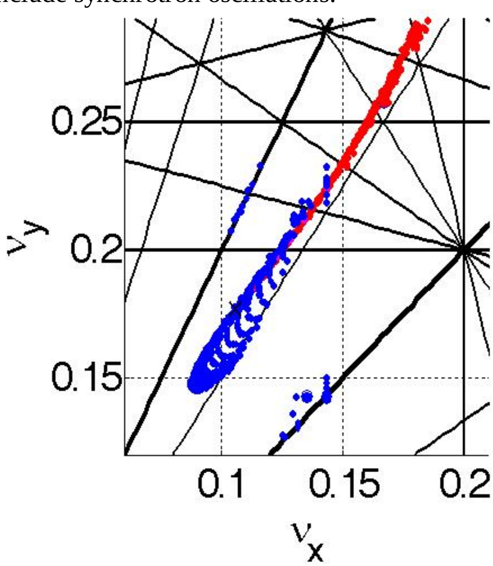

Figure 5: Measured tune map in (x, δ). Red is positive energy shifts, and blue is negative.

From data taken for Fig. 5, we derived the nonlinear chromaticity plots shown in Fig. 6. To make Fig. 6, we first adjusted to model sextupoles, so the model linear chromaticity agreed with the measured chromaticity. The plots have the linear term in the chromaticity subtracted in order to make the nonlinear terms clearly visible. The discrepancy in the vertical chromaticity plot is another indication that we need to improve our magnet models.

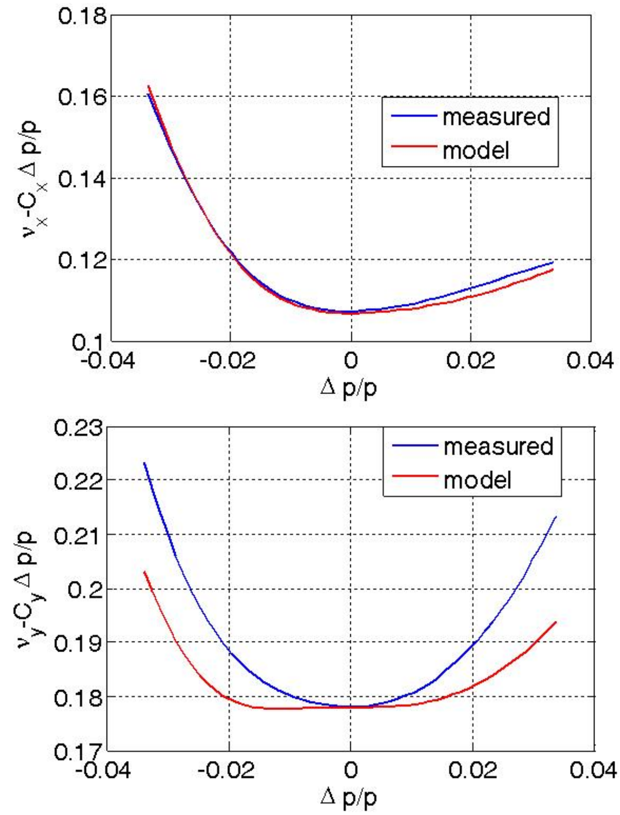

Figure 6: Measured and model nonlinear chromaticity in x (top) and y (bottom).

SUMMARY

We have developed measurement techniques for characterizing the nonlinear dynamics of the SPEAR3 storage ring. Our improved understanding has guided us in implementing a low emittance optics. The measurements indicate significant differences between our model and the real ring. We will work to improve the nonlinear model of our magnets to obtain better agreement with measurements.

ACKNOWLEDGEMENTS

We would like to thank Don Martin for help setting up hardware for our measurements.

REFERENCES

[1] D. Robin et al., "Global dynamics of the Advanced Light Source revealed through experimental frequency map analysis", Phys. Rev. Lett. **85**, 558, (2000).

[2] P. Kuske, "Effects of fringe fields and insertion devices revealed through experimental frequency map analysis", PAC'05, WOAC003, (2005).

[3] J. Sebek, "Beam Position Monitor System Electronics Design", May 7, 2003, unpublished.

[4] W. Cheng et al., "Fast Gated Camera Measurements in SPEAR3", these proceedings.

[5] J. Sebek, D. Arnett, J. Langton, C. Pappas, "SPEAR3 injection kicker," PAC'01, Chicago, 2001, p. 1592.