

SPEAR3 COMMISSIONING

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Abstract

The successful commissioning of the new SPEAR3 light source at the Stanford Synchrotron Radiation Laboratory (SSRL) will be reviewed. Orbit control, beam-based alignment, and an orbit interlock were commissioned. Orbit motion was characterized as a function of frequency. The linear optics was corrected for ID focusing and coupling errors. The nonlinear optics were investigated with dynamic aperture measurements as a function of energy and tune.

INTRODUCTION

The SPEAR storage ring was built in 1972 as an e-/e+ collider at Stanford Linear Accelerator Center. In 1989 it became a fully dedicated synchrotron light source for SSRL. The SPEAR3 project is a complete rebuild of the storage ring, from a new concrete floor up [1]. The new storage ring maintained only the original geometry, rebuilding the 18 cells of the ring about the existing 7 insertion devices and 4 dipole beamlines. SPEAR3 provides higher brightness, increased stored current, and better beam stability. The horizontal emittance has been reduced by nearly a factor of ten to 18 nm*rad, and the storage ring is capable of storing up to 500 mA.

Because SSRL was an operating light source with an active user community prior to SPEAR3, a speedy installation and commissioning was essential. The entire process lasted 11 months, with removal of the old SPEAR storage ring starting on March 31, 2003. Eight months later, on December 9, SPEAR3 started a three-month commissioning period. First beam to SPEAR3 was on December 10, with first accumulated beam on December 15. On January 22, 100 mA was stored, and March 15 saw the start of user operations.

The commissioning team included experts visiting from light source laboratories worldwide. The visitors typically came for periods of a week or two, and their experience and expertise helped to ensure rapid commissioning success.

CONTROL SYSTEM

A flexible and adaptable MATLAB interface to an EPICS control system enabled the commissioning group to quickly develop code for measurements and to rapidly respond to issues arising while commissioning the various

storage ring systems. This MATLAB code was ported from the ALS [2] with many improvements for SPEAR3 [3]. Measurement data going directly to MATLAB greatly facilitated data analysis and plotting.

A web-based electronic logbook [4] was used to record commissioning results. In this way the team was easily kept up to date on commissioning issues and progress.

DIAGNOSTICS

The diagnostics available during commissioning were a Bergoz DCCT, a stripline tune driver, and 112 BPMs, 54 of which had Bergoz electronics [5]. In the coming months we expect to bring online the first set of 18 Echotek [6] BPM electronics with digital receivers, capable of turn-by-turn as well as low-noise closed orbit measurements. In addition, we will have an x-ray pinhole camera [7], a UV synchrotron light monitor [8], and horizontal and vertical scrapers.

The BPM orbit readings are updated at 4 kHz. For closed orbit measurements, we typically average 0.5 seconds of data (2000 consecutive readings). The typical rms variation for 0.5 second data is 100 nm, most of which can be attributed to real orbit motion. The noise level for 4 kHz data is about 5 microns.

COMMISSIONING RESULTS

Closed orbit

The measured closed orbit with all steering magnets off has peaks under 4 mm horizontally and 2 mm vertically. The small closed orbit shows the ring is well aligned.

Beam-based alignment [9] was used to determine that the 54 BPM offsets in both planes were 0.7 mm or less. The reproducibility of the beam-based alignment was 2 μm rms for data sets taken 3 hours apart, and 23 μm rms for data sets taken 38 days apart.

An orbit interlock protects the vacuum chamber from mis-steering of high power insertion device (ID) radiation. The orbit is monitored on BPMs upstream and downstream of each ID. If the orbit at the center of the ID (y, y') gets beyond the trip level,

$$\frac{|y|}{1.2 \text{ mm}} + \frac{|y'|}{0.36 \text{ mrad}} < 1 \quad (1)$$

the beam is dumped within 2 msec.

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Orbit drift

The orbit stability specification for SPEAR3 is $<10\%$ of the beam size, which comes to 3 to 5 microns vertically and 16 to 43 microns horizontally, depending on the beamline source point. Great effort was made in the SPEAR3 design to minimize orbit motion [1].

During commissioning, measurements were made to characterize both the slow orbit drift and the orbit motion at frequencies above 1 Hz. The orbit drift over the course of 10 hours with no orbit feedback had peaks of about 100 μm in x and 50 μm in y .

Beam-based measurements were made of electronics intensity dependence. The measured orbit shift between 100 mA and 50 mA (the typical range of currents that will be used in the first year of operations) was 3.4 μm rms in x and 3.0 μm in y .

Orbit jitter

The power spectral density was derived from the 4 kHz BPM data. The measured PSD for orbit jitter between 2 and 200 Hz integrates to 3.7 μm horizontally and 2.2 μm vertically, within the orbit stability specification.

Orbit feedback

A MATLAB-based slow orbit feedback which corrects the orbit every six seconds was implemented for the start of operations. The feedback uses all 54 steering magnets in each plane and holds the measured orbit shift at the 54 Bergoz BPMs to well under 1 μm over the course of a fill.

The hardware is in place for a digital fast orbit feedback using the 4 kHz BPM data to correct orbit motion out to ~ 200 Hz. This system will be commissioned during the first year of operation.

Optics

Most of the optics characterization and correction was done by analyzing closed orbit response matrix data with the LOCO code [10]. LOCO was also used to calibrate and correct the tunes, betas and dispersion functions, correct for insertion device focusing, calibrate the BPM gains and steering magnet strengths, correct the coupling and vertical dispersion, and measure the local chromaticity and transverse impedance distributions. The vertical beam size was minimized by correcting the off-diagonal elements of the orbit response matrix and the vertical dispersion [12].

Nonlinear transverse dynamics

To characterize the nonlinear dynamics, we measured the local chromaticity correction, the nonlinear chromaticity, the dynamic aperture as a function of RF frequency and as a function of transverse tunes, the lifetime as a function of RF gap voltage and as a function of transverse tunes, and the lifetime as a function of vertical physical aperture.

The local chromaticity correction was verified by measuring two orbit response matrices, one with the RF frequency set at +5 kHz and one at -5 kHz from nominal.

Each response matrix was fit with LOCO to get the betatron phase advance around the ring. The difference in phase advance gives the local chromaticity, confirming that the sextupoles are all working correctly.

Figure 1 shows the measured horizontal dynamic aperture as a function of energy with insertion devices closed. With IDs open, the dynamic aperture was about 20% larger. The data was taken by filling 1 mA, then increasing the strength of single injection kicker until the beam was kicked out of the ring. This was repeated for varying RF frequency.

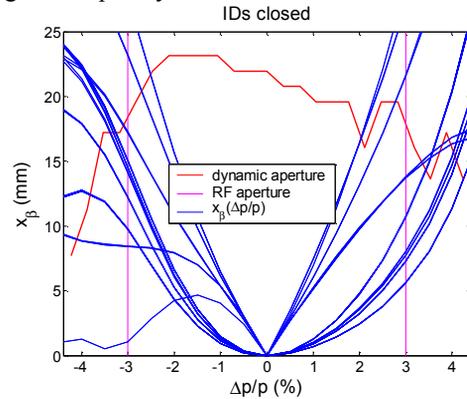


Figure 1: Measured horizontal dynamic aperture vs. energy, IDs closed.

The blue curves plotted in Fig. 1 give the horizontal oscillation amplitude that would be excited for the given energy shift, depending on where in the ring the energy shift occurred. Each straight section has a different blue curve, depending on the nonlinear dispersion and beta functions. The intersections of the blue curves and the dynamic aperture give the dynamic energy aperture [13].

The dynamic energy aperture was also determined by measuring the lifetime vs. RF gap voltage. The measurement was made with 8 mA in a single bunch to get in the Touschek lifetime regime. Figure 2 shows a plot of the data along with a fit line giving Touschek scaling. The data deviates from Touschek scaling at low gap voltages, where quantum lifetime effects become significant. The data starts to diverge from the line for increasing energy acceptance at about 2%. This indicates that the dynamic energy acceptance is 2% for some of the straight sections, consistent with the results in Fig. 1.

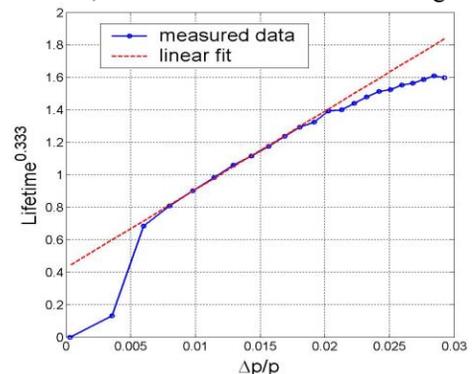


Figure 2: Cubed root of lifetime vs RF energy acceptance, ID gaps closed.

Figure 3 shows the measured dynamic aperture as a function of horizontal and vertical tune. This data was collected automatically over the course of several hours using a MATLAB script. For each data point, the tunes were adjusted to a point on a grid, and a single injection kicker was raised until the stored beam was kicked out.

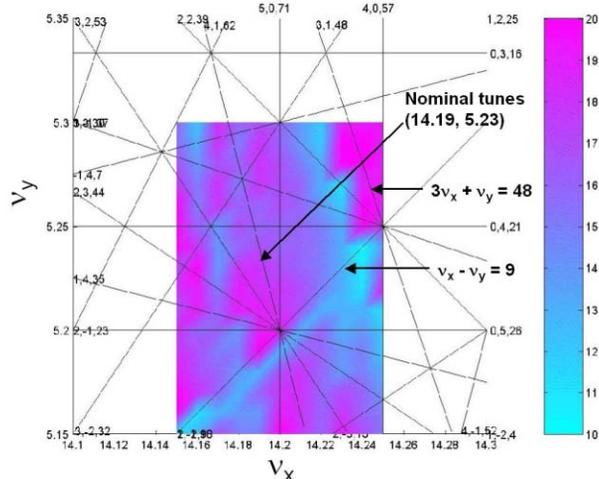


Figure 3: Measured dynamic aperture (maximum kicker strength) vs. transverse tunes.

Figure 3 shows some resonant features. The dynamic aperture decreases along the difference coupling resonance, and along the $3v_x + v_y$ resonance. The reduction in dynamic aperture along the $3v_x + v_y$ resonance is offset from the resonance line due to the tune shift with amplitude. The zigzag along this resonance is simply a plotting feature associated with the density of data points.

The lifetime was also measured as a function of transverse tunes. Lifetime degradation was seen along the difference resonance.

Longitudinal dynamics

When injection was first attempted in SPEAR3, all sextupoles were left off. The assumption was that on day one, the closed orbit errors would be large. Large orbit distortions in the sextupoles distort the transverse optics and degrade the dynamic aperture. So sextupoles were left off to improve the transverse dynamics.

We had difficulty storing beam with sextupoles off. Longitudinal tracking studies and measurements showed that the acceptance is greatly reduced without sextupoles, due to a large increase in the second order momentum compaction factor, α_2 .

Impedances & instabilities

During the commissioning period, radiation protection requirements limited the beam to 100 mA. SPEAR3 was designed for 500 mA, and we hope to attempt to fill to 500 mA sometime during the first year of operation.

With 100 mA stored, we initially saw spontaneous excitation of vertical betatron oscillations. The oscillations, however, were at the mode frequencies associated with ion instabilities, and they have all but

disappeared as the vacuum has improved. We also see some excitation of longitudinal oscillations. Rather than beam instabilities, these appear to be driven oscillations (probably by the RF), which we will work to eliminate.

With the chromaticities corrected to +1 in each plane, the single-bunch stored current limit is 25 mA.

CONCLUSION

The control system and diagnostics available for SPEAR3 commissioning enabled the commissioning team to gather and analyze a substantial amount of data in a relatively short time. After only three months, the SPEAR3 storage ring orbit, optics, and nonlinear dynamics have been well characterized and controlled.

ACKNOWLEDGEMENTS

We would like to commend the SPEAR3 staff for their work during and before commissioning. The speed at which commissioning proceeded is a testimony to the fine work that went into designing and building SPEAR3. The experience and energy of the SSRL operations group was also a great benefit during commissioning.

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