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NONLINEAR DYNAMICS IN THE SPEAR3 DOUBLE-WAIST CHICANE*

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Abstract

One of the two 7.6 m long straight sections in SPEAR3 has been divided into two short straights to provide places for two new small-gap insertion devices (IDs) [1,2]. A chicane generates an angular separation of 10 mrad between the two straights. A quadrupole triplet has been added in the center of the 7.6 m long chicane to create a 'double-waist chicane' optics with β_y=1.6 m at the center of each of two future IDs. The new optics also reduces β_y to 2.5 m in the four 4.8 m straight sections. In this paper, we discuss nonlinear dynamic studies associated with design and implementation of the new optics. We present tracking results generated during the design stage and compare them to nonlinear dynamics measurements made with the quadrupole triplet installed in SPEAR3.

INTRODUCTION

The double-waist chicane optics were designed over the course of four years, culminating in final optics design reviews in 2004 [1]. Details of the linear optics design can be found in these proceedings [2]. The new optics has reduced β_y at six locations, with stronger focusing, higher vertical tune and chromaticity, and stronger sextupole strengths. The new quadrupole triplet was installed in SPEAR3 in summer, 2005, to enable testing of the new optics during the 2005-2006 run. Measurements over the past several months have shown that the optics perform as expected, with good injection and lifetime. Delivery of user beam in the new optics will start this fall.

This paper will present the nonlinear dynamics tracking studies that were done for the 2004 optics design reviews, and will compare the tracking to subsequent beam measurements.

TRACKING STUDIES

Figures 1 and 2 compare dynamic aperture tracking in AT [3] for the old optics and the new, double-waist chicane optics. The tracking setup includes:

- Symplectic integration for insertion devices [4], including BL11 with end correctors [5].
- Random and systematic magnet multipoles.
- 5 mm vertical physical half aperture from IDs.
- ~15 random magnet error seeds, each with 1% beta-beat and coupling.
- 10,000 turns, synchrotron oscillations, radiation, $\xi_{x,y}$=+1.0,+1.25.

Tracking without insertion devices (IDs) showed that the old optics had a larger dynamic aperture, but with IDs the dynamic apertures are comparable (Figs 1, 2). The aperture for negative x is particularly important, because the injected beam arrives on the inside of the ring. The off-energy (blue) dynamic aperture is also similar in the old and new optics. This is critical for the two dominant lifetime effects in SPEAR3: bremsstrahlung and Touschek scattering.

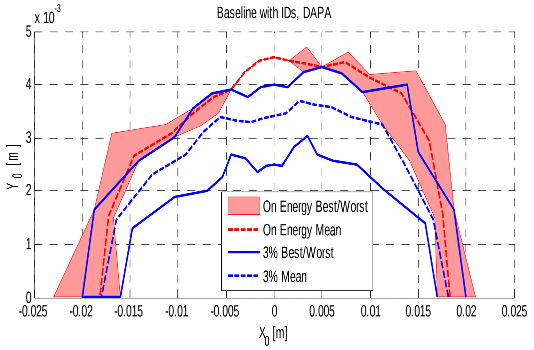

Figure 1: Dynamic aperture tracking at injection point for old optics with IDs. Envelope shows multiple error seeds.

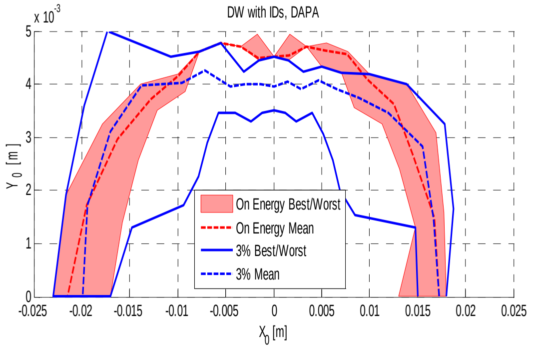

Figure 2: Dynamic aperture tracking for the new optics with IDs. Envelope shows multiple error seeds.

Figure 3 is a frequency map [6,7] in the new optics in which the color code is an exponential scale for the rate of tune diffusion. Figure 4 shows this same tune diffusion as a function of initial coordinates (x_0, y_0).

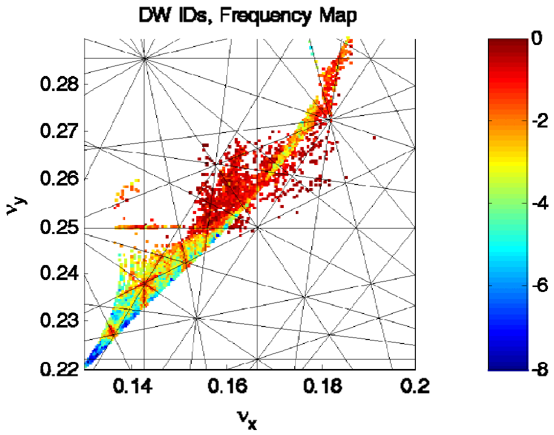

Figure 3: Frequency map tracking, new optics, IDs closed

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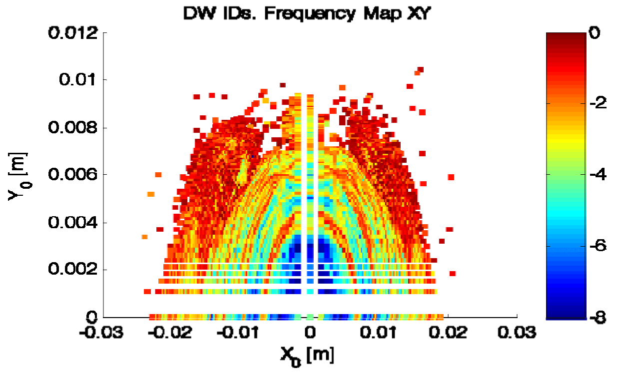

Figure 4: Frequency map tracking, new optics, IDs closed

The arcs of high diffusion starting at x_0 = +/- 8 and 10 mm in Fig. 4 initially led to concern that x oscillations would couple into y and get lost on vertical apertures of the ID chambers, severely limiting the effective dynamic aperture in x. The tracking results shown in Fig. 5, however, indicated that the new optics would not have this problem. A dense grid of initial (x_0,y_0) launch points were tracked with radiation losses included, and the largest y reached for each initial point is given by the color code. The new optics look better than the old by this measure, and neither optics shows significant x-to-y nonlinear coupling for x_0<15 mm.

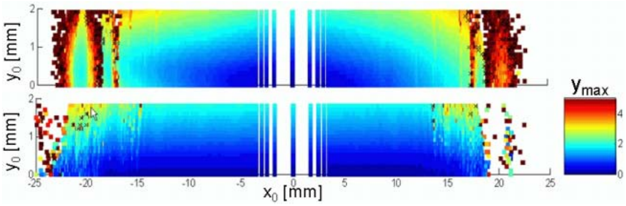

Figure 5: $y_{max}(x_0,y_0)$ for old optics (top plot) and new optics (bottom plot) with IDs closed and radiation losses.

BEAM MEASUREMENTS

Because SPEAR3 does not have a vertical or longitudinal kicker at this time, the beam dynamics measurements do not correspond directly to tracking studies in all cases. The off-energy measurements were made for fixed energy, controlled with rf frequency, while the tracking was made with synchrotron oscillations. What's more, the tracking was done with the horizontal and vertical chromaticities corrected to +1.0 and +1.25 while the measurements were made with chromaticities set to +2.0 and +2.0, values that were found to be required to fully damp the resistive wall instability at 500 mA. Nonetheless, the following measurements confirm many of the tracking conclusions.

Figure 6 shows the measured horizontal dynamic aperture as a function of energy in the old optics and the new optics. The measurements were made with all the IDs opened and again with all IDs closed. For each graph point, 4 mA was distributed in 80 consecutive rf buckets; the rf frequency was adjusted to fix the beam energy; and a single injection kicker strength was increased until the beam was lost. The betatron oscillation amplitudes were determined using turn-by-turn BPMs with Echotek digital receivers [8]. The measurements confirm the following tracking results:

- IDs reduce the dynamic aperture more in the old optics than the new.
- With IDs the dynamic aperture in the new optics is about the same as in the old optics.
- The dynamic energy acceptance is limited for the most part by the 3 % rf acceptance.

The on-energy horizontal dynamic aperture is slightly smaller than predicted in figs. 1 and 2, but that could be due to larger chromaticities for the measured data.

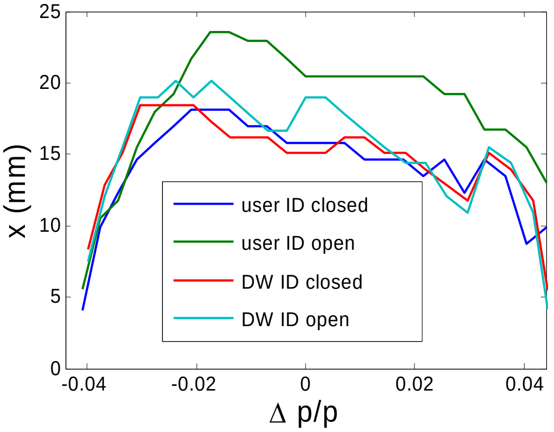

Figure 6: Measured dynamic aperture vs. energy.

Figures 7 and 8 show $(x_\beta, \Delta p/p)$ tune maps for the new optics measured with IDs open and closed. The tune maps were recorded during the dynamic aperture measurements shown in Fig. 6. For each rf frequency (fixed $\Delta p/p$), an injection kicker strength was increased in steps. At each step the turn-by-turn BPM data was used to determine the tunes. The color scheme, blue to red, indicates increasing x_β. The red dot shows the unperturbed tunes. Starting from the red dot, the blue points moving up and to the right are increasing energy (+2 chromaticities); blue points down and to the left are decreasing energy.

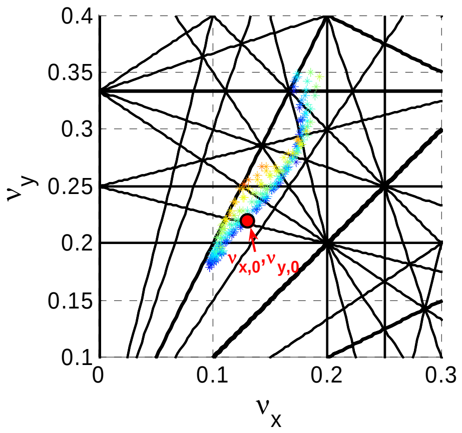

Figure 7: Measured $(x_\beta, \Delta p/p)$ tune map, new optics, IDs open.

The increased clustering of points on the $2\nu_x-\nu_y$ line in Fig. 8 shows that the IDs enhance the strength of this skew sextupole resonance. We measured the dynamic aperture with the working point closer to this resonance, and found a reduction in off-energy aperture.

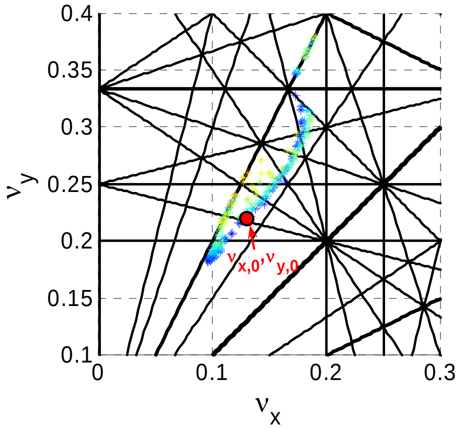

Figure 8: Measured (x_β, $\Delta p/p$) tune map, new optics, IDs closed.

Figure 9 compares measurement and tracking of tune shifts with x_β amplitude ($\Delta p/p=0$). The agreement for ν_x is remarkably good. The small discrepancy for ν_y is consistent with other errors we have seen in the vertical optics. For example, the model and measured vertical tunes differ by .017, and the vertical chromaticity also has a small error. We believe the discrepancies in the vertical optics are primarily associated with dipole end field modeling errors.

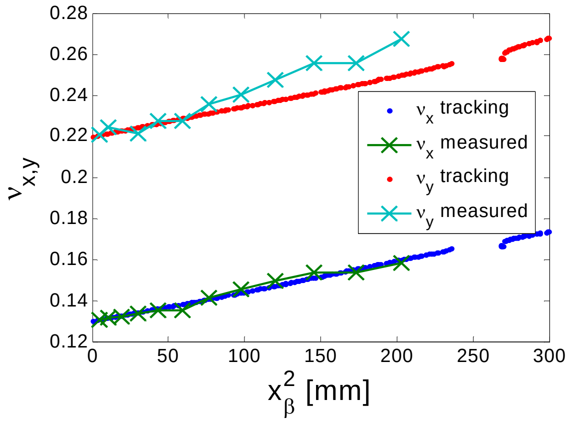

Figure 9: Tune shift with amplitude, measurement and tracking in new optics with IDs closed.

Figure 10 shows the measured lifetime vs. vertical scraper position with 100 mA stored beam. The smooth reduction in lifetime with vertical aperture indicates no serious problem with resonant coupling of horizontal betatron oscillations into the vertical plane, a result consistent with the tracking (Fig. 5). The data sets for the two optics were taken several months apart, so the ~15% difference in lifetime for the scraper removed (right side of Fig. 10) could be attributed to different gas pressure or vertical beam size correction. To within measurement error, the lifetime in the new optics remains unchanged.

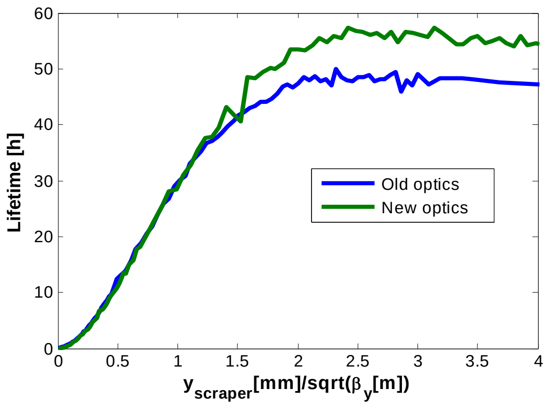

Figure 10: Measured lifetime vs. vertical scraper position, old optics and new optics, IDs closed.

CONCLUSION

Beam measurements have confirmed the accuracy of our SPEAR3 tracking. The lifetime, injection, and dynamic aperture in the new double-waist chicane are consistent with model predictions. We are ready to start operations in the chicane optics in the autumn of 2006.

ACKNOWLEDGMENTS

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