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SPEAR3 ACCELERATOR PHYSICS UPDATE*

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Abstract

The SPEAR3 [1,2] storage ring at Stanford Synchrotron Radiation Laboratory has been delivering photon beams for three years. We will give an overview of recent and ongoing accelerator physics activities, including 500 mA fills, work toward top-off injection, long-term orbit stability characterization and improvement, fast orbit feedback, new chicane optics, low alpha optics & short bunches, low emittance optics, and MATLAB software. The accelerator physics group has a strong program to characterize and improve SPEAR3 performance.

INTRODUCTION

In this summary of the past three years of accelerator physics at SPEAR, we will focus on subjects not yet covered in separate accelerator conference papers. Topics that have already been written up elsewhere will be briefly summarized and referenced.

500 mA

The SPEAR3 vacuum chamber was designed for 500 mA. The existing photon beamlines, however, were built for the SPEAR2 operating current of 100 mA. In order to run at 500 mA, the photon beamline optics are being upgraded to handle higher power loads, and the beamline radiation shielding is being upgraded to handle the higher radiation levels.

In the mean time, accelerator physics studies have proceeded with the photon beamlines closed to show that SPEAR3 runs well at 500 mA. We have found that the SPEAR3 beam is inherently stable at 500 mA without the need for multi-bunch feedbacks, so long as the non-normalized chromaticities are set to +2 in both planes. This confirms predictions for the copper vacuum chamber with mode-damped RF cavities. Below +2 in chromaticity, we see evidence of resistive wall instability.

The measured lifetime at 500 mA is 14 hours.

TOP-OFF INJECTION

The increased power load on the photon optics associated with 500 mA running is driving our push toward top-off injection. The thermal transients associated with closing photon beamline shutters during injection will become much worse at 500 mA.

Before top-off injection can start, we must prove that it is safe to inject beam with photon shutters open [3]. We are conducting a study to prove by simulation that injected electrons cannot escape down photon beamlines under a wide range of conditions, including lattice tuning, orbit feedback operations, and possible magnet failures and pole shorts. The layout of a typical beamline is shown in Fig. 1.

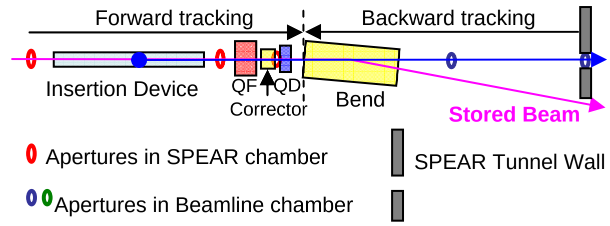

Figure 1: Beamline layout for top-off tracking.

The simulations consist of three steps: 1. Forward tracking in the upstream straight section. 2. Backward tracking in the photon beamline. 3. Comparing tracked phase spaces at an intermediate point to establish there is no overlap (Fig. 2).

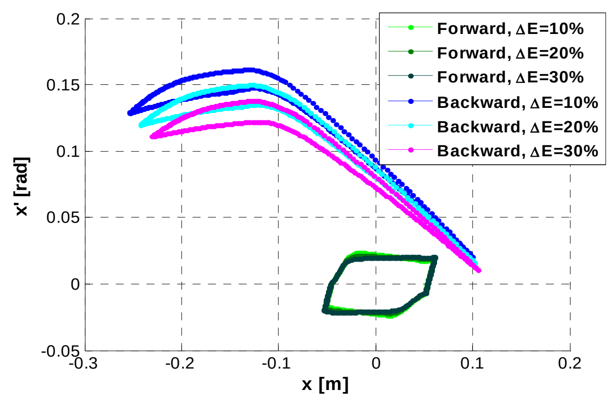

Figure 2: Forward and backward tracked phase spaces do not overlap, indicating top-off is safe.

Simulations show that the safe, no-overlap, condition is most sensitive to the energy error of the injected beam, QF quadrupole strength, and dipole field error. For these three parameters we will design hardware interlocks. A stored current interlock will act as a dipole field interlock, limiting field error to <10%.

Top-off injection will also require significant improvements in the stability and performance of the SSRL injector. There is much on-going work with the injector to achieve this goal, including doubling the energy of our linac, realigning the booster, rebuilding our booster to SPEAR transport line vacuum, and adding and improving diagnostics and controls throughout the injector.

Work is ongoing to reduce perturbation of the stored beam from firing the injection kickers [4] during top-off. Initially, we measured stored beam oscillations of 1 mm peak-to-peak vertical, and 0.5 mm horizontal.

The vertical oscillations were from nonlinear horizontal

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leakage field in our Lambertson injection septum. We have now nearly eliminated the vertical oscillations with a unique nonlinear 5-pole correction magnet installed just before the septum as well as skew quadrupoles in nearby sextupoles.

The horizontal oscillations arise from kicker bump mis-match with amplitude due to sextupole magnets within our 3-magnet kicker bump, and due to transverse variation in the field integral of our central kicker. We have demonstrated that we can greatly reduce both effects by narrowing the pulse width of the central kicker. Work is also ongoing to reduce kicker impedance mis-match reflection transients.

We plan to start injection with photon shutters open toward the end of the 2007-2008 run. Top-off operations with 500 mA should start soon thereafter.

ORBIT STABILITY

During SPEAR3 commissioning and the first two years of running, a MATLAB-based slow orbit feedback was used to correct the orbit every six seconds. In 2006, this system was replaced with a fast orbit feedback with a bandwidth of about 100 Hz [5]. For electron BPMs in the feedback system, orbit drift was reduced to 0.1 µm, and orbit jitter from 1 to 100 Hz is a couple microns rms. Unfortunately, this does not tell the whole story. Photon BPMs indicate orbit drift of tens of microns over the course of many minutes or hours.

Investigation of this drift showed that the dominant part came from temperature dependence of the electron BPM electronics. Figure 3 shows an example of the correlation between the temperature in the electron BPM electronics rack and the measured position at a photon BPM over 24 hours. Since this data was taken, temperature controlled rooms have been built around the electron BPM electronics to eliminate this problem.

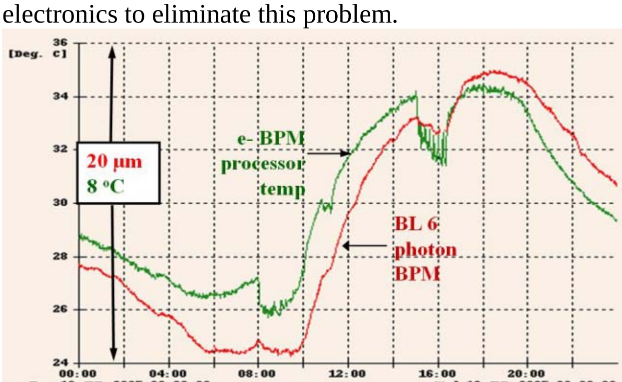

Figure 3: Correlation between electron BPM electronics temperature and photon beam motion over 24 hours.

Now that the drift from BPM electronics temperature dependence has been mitigated, we are investigating other sources of error in the electron BPM readings. We are building an invar stand to measure mechanical movement of the BPMs with respect to the floor. We are also working with a hydrostatic leveling system to measure variations in the height of the floor within the storage ring tunnel and at the photon beamlines. Figure 4 shows some measurements [6] from the hydrostatic leveling system showing relative variations in the floor height over the course of 1.5 years. We see a maximum of about 300 microns in differential floor motion between two locations in the accelerator tunnel separated by 24 meters.

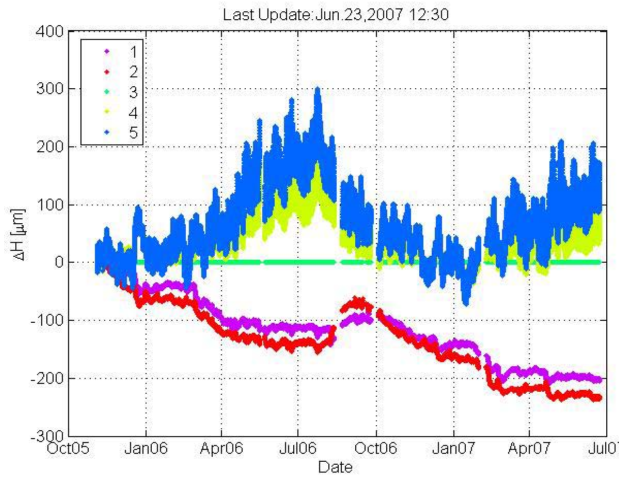

Figure 4: Measured variations in floor height over the course of several months.

When we remove an electron BPM from the orbit feedback, we see tens of microns orbit motion at that BPM. Figure 5 shows the strong correlation between the orbit motion measured at a BPM removed from the feedback and the local tunnel temperature over 7 days.

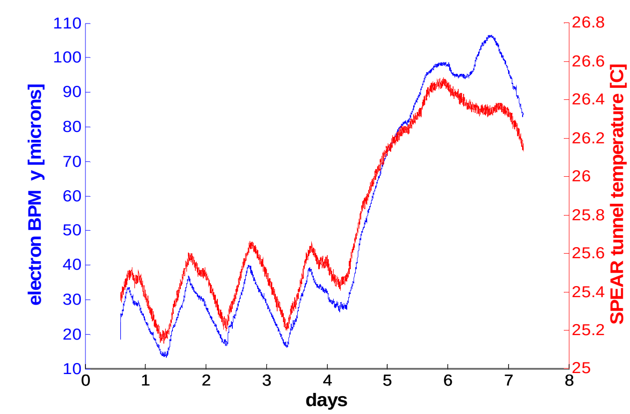

Figure 5: BPM removed from orbit feedback for 7 days.

Temperature related orbit drift has been somewhat mitigated by integrating photon BPMs into the orbit feedback and using pitch feedback on photon mirrors. Work is ongoing to determine how best minimize tunnel temperature variations.

OPTICS UPGRADES

Low Emittance Optics

On May 2, 2007, SSRL switched from an achromatic optics to a low emittance optics with 10 cm dispersion in the insertion device straights. Figure 6 and table 1 compare the achromatic to the low emittance optics.

In order to avoid lifetime reduction in the low ε_x optics, we are presently we are using the 13.7 pm ε_y option in operations, because most beamlines are unable to resolve a 6.8 pm ε_y. When we switch to top-off, we will correct ε_y to 6.8 pm, because lifetime will be less important.

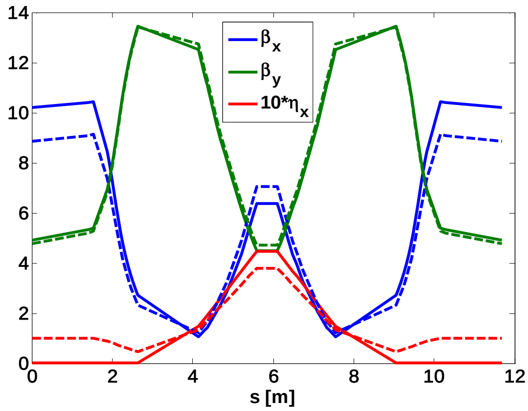

Figure 6: Achromatic (solid) and low emittance (dotted) lattice functions for a single SPEAR3 arc cell.

Table 1: Low emittance optics parameters

Optics	Achromat	Low ε_x
ε_x [nm] no IDs	18.0	11.2
ε_x [nm] w/IDs	15.0	9.8
ε_y [pm]	7.5	6.8/13.7
σ_x [mm] IDs	391	311
σ_y [mm] IDs	6.1	5.7/8.1
$\sigma_{x'}$ [mrad] IDs	38	33
$\sigma_{y'}$ [mrad] IDs	1.2	1.2/1.7
τ [hr] @100 mA	48	41/49
τ [hr] @500 mA	14	11/14

Reduced dynamic aperture in low ε_x has lead to ~30% smaller typical injection rates. Injector improvements associated with top-off should eliminate this problem.

Short Bunches in SPEAR3

With the SPPS, LCLS and Ultrafast Science Center, the photon user community interested in short photon pulses at SLAC is growing. We have developed low-alpha optics in SPEAR [7], in which we've measured bunch lengths as short as 2.5 psec rms [8-10], compared to the achromatic lattice bunch length of 17 psec.

Photon beamline developments are underway for using the short pulses in the upcoming 2007-2008 run.

There have also been tracking studies of injecting short, higher current bunches into SPEAR, which would maintain short bunch lengths for tens of turns [11].

Double Waist Chicane Optics

In 2006, we implemented an optics upgrade, adding a quadrupole triplet to one long straight section and reducing the vertical beam size (βy) to allow smaller gap insertion devices in up to six straight sections [12,13]. An in-vacuum undulator with a minimum gap of 5.5 mm was installed in of these straights; an elliptically polarized undulator will be installed in another straight during summer 2007.

MATLAB SOFTWARE DEVELOPMENT

MATLAB middlelayer [14.15] development is continuing, including a satellite meeting at this conference. LOCO has recently been upgraded to allow constraints on fit quadrupole gradients, which helps the code converge to reasonable solutions for many storage rings. The MATLAB middlelayer is now being used at accelerator laboratories worldwide.

ACKNOWLEDGEMENTS

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