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RECENT PROGRESS IN INJECTOR IMPROVEMENT OF SPEAR 3*

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Abstract

The frequent injection and high current operation of SPEAR 3 storage ring requires high stability of the injector system at the Stanford Synchrotron Radiation Laboratory (SSRL). The lattice of linac-to-booster (LTB) transport line was not well understood and controlled prior to this work. In this paper, we discuss the significant efforts that have been made to improve the performance of the LTB. A method to correct the distortion of the closed orbit in the booster by moving 2 quadrupoles is also presented.

INTRODUCTION

SPEAR3 is a third generation light source at SSRL which began user operations in March, 2004 [1]. Starting in June 2010, a frequent fill schedule with 10 minutes between SPEAR3 injections has been employed [2] in order to implement top-off injection, injecting with SPEAR3 photon beam lines open. Instead of the original manual fills three times a day, automatic injections are conducted every 10 minutes which maintain the SPEAR3 current stability to approximately 1%. The SPEAR3 storage ring currently is operating at 300 mA and will eventually be operated at the design value of 500 mA once the beam lines are approved for higher current operation. Therefore a higher injection rate to the storage ring and stable operation of the injector are highly desired for the future operation of SPEAR3.

The SPEAR3 storage ring is fed by a dedicated injector system consisting of a short linear accelerator with a beam energy of about 120 MeV as a preinjector, a 3GeV booster ring, and a booster-to-SPEAR (BTS) beam transport line injecting the particles into the SPEAR3 storage ring.

LTB OPTICS CONTROL

Overview

The LTB section of the injector was originally designed and commissioned in early 1990s [3]. The layout of the LTB transport line is shown in Fig. 1. It consists of three bending magnets (B1-B3), six quadrupoles (Q1 to Q6), a septum, an injection kicker, and multiple steering magnets in each plane. The beam diagnostic tools in LTB section include a phosphor screen, a toroid for measuring the total charge of the beam after the first bending magnet, and six BPMs with Bergoz electronics. The total length from the exit of Linac to the end of the injection kicker is about 14.45 m.

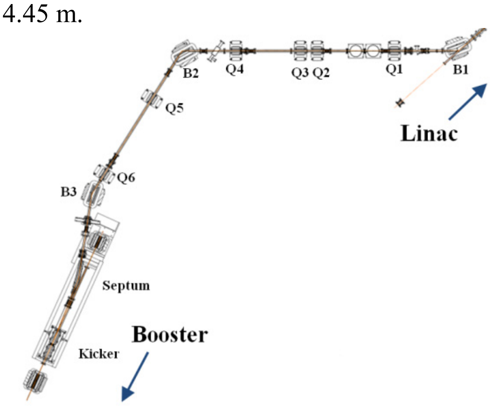

Figure 1: LTB layout from LINAC to Booster

Penetrating through a shielding wall between the Linac hall and the booster tunnel, the LTB transport line is located in two different vaults. B1 and Q1 are contained inside the Linac hall. Q2 and Q3 are right inside the penetration, through which line-of-sight access is impossible without breaking the LTB vacuum. All components from B2 to the end of LTB are hidden behind two booster girder sections, supporting vacuum chambers, magnets and other accelerator equipment. The BTS transport line is located immediately above these same booster girders. Thus, access to components downstream of B2 is only possible after removing a booster girder or parts of the BTS transport line.

To maintain a stable injection to the SPEAR3 storage ring from the injector, the operators established the operating LTB lattice empirically without concern of the detailed optics in the front end of the injector. As a result, the beam trajectory was displaced from the centers of most LTB BPMs.

Alignment of the LTB

After carefully calibrating the polarities of all magnets and the strengths of all correctors, beam based alignment (BBA) was attempted to steer the beam through the center of all quadrupoles and identify a reference trajectory. However, it was impossible to align the beam to the center of the first four quadrupoles simultaneously without losing beam between B1 and B2. The beam could be steered close to the center of Q1, Q3, and Q4, but a large offset would always remain from the center of Q2. Serving as a horizontal corrector, trim coils wound inside the core of Q2 allowed us to estimate the amount of beam offset from its center in the horizontal plane. As the strength of this corrector was known, the linear transport matrix

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between Q2 and downstream BPMs could be measured by scanning it. Then the offset at Q2 was measured directly by scanning its strength. The measurement results shows that even with the best efforts in steering, the offset in Q2 was still larger than 6-7 mm.

The problems revealed by BBA led to a decision to conduct a comprehensive alignment survey during the SPEAR3 downtime in the summer of 2010. Because of the difficult layout, this had not been done since the injector was first commissioned. Two survey holes were drilled through the linac/booster wall in order to link the coordinate systems on either side, and a booster girder was removed to gain access to the transport lien after B2.

The survey revealed many misalignments relative to the design layout, including the following:

- The centers of the six quadrupoles were misaligned in the horizontal plane by 1.97, 6.42, 5.47, 4.63, 3.72, and 2.72 mm.
- The B1 and B2 bending magnets, which are sector-to-rectangular hybrids, had significant alignment errors. For example, an electron entering B1 on the design trajectory exited the magnet with a (parallel) horizontal displacement of -8.6 mm.

Given the constraints on magnet movements in LTB, a new design trajectory was implemented and the positions of most elements corrected. Subsequently, the transmission through the LTB is much less sensitive to magnetic field values. The beam can now also be easily steered to the center of all BPMs and Quads.

Nonlinear Dynamics

To control the beam orbit in the LTB, a linear orbit correction program based on SVD and the measured LTB response matrix has been developed. However, the code does not work as expected due to large nonlinear dynamics that have recently been found in the second bend B2.

Table 1: Parameters for LTB bends

	B1	B2	B3
Angle (degrees)	41.569	57.755	23.337
Sagitta (mm)	41.63	57.99	22.28
Width (mm)	120	120	120

As shown in Table 1, B2 has the largest bending angle and Sagitta among all the bends, but a relatively small width. As a result, the beam will inevitably experience nonlinear field roll off in B2. This is believed to cause the inconsistency between measured response matrix and the model matrix obtained from MATLAB accelerator toolbox (AT) [4].

The effect of the nonlinear fields in B2 on the beam has been experimentally observed from the nonlinear curving motion of the beam in the BPMs downstream of B2, when scanning a vertical corrector upstream from B2 with all magnets between them other than B2 being off. The nonlinear component in B2 is difficult to characterize because of its sensitivity to the beam trajectory inside B2.

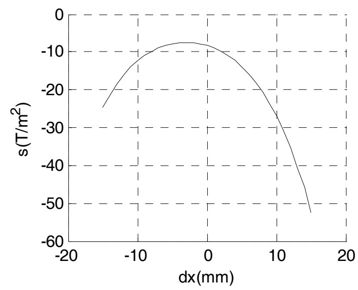

Figure 2: Sextupole term v. s. orbit distortion in B2.

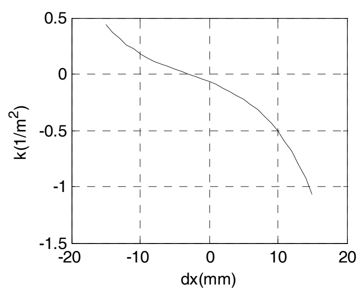

Figure 3: Quadrupole term v.s. orbit distortion in B2.

Using the horizontal magnetic field roll-off data of B2 measured about 20 years ago, we calculated the integrated sextupole and quadrupole term seen by the particle having an offset from the design orbit. As shown in Figures 2 and 3, there is a large dependence of the sextupole and quadrupole terms on beam trajectory if we assume B2 is a sector magnet. The real geometry of B2 is a sector magnet at the entrance and a rectangular magnet at the exit. This introduces even stronger magnetic multipole field-variations at different cross sections, hence may generate stronger nonlinear effects on the beam passing through B2. Currently, simulations based on the mechanical dimensions of the poles and coils of B2 are being carried out in order to solve for the magnetic field distribution in B2 numerically. These results should shed a light on making a more realistic model of B2 in AT and further help us understand and control the LTB optics.

BOOSTER ORBIT DISTORTION

The booster has 32 H-type bending magnets and 40 quadrupoles, 20 each QF and QD. They are powered by a resonant network power system (White Circuit) [5]. This means the bending magnets and the two quadrupole families are powered in series and have the same current. 40 BPMs are evenly distributed along the ring and 21 of them are connected [6].

For an ideally aligned lattice and BPMs without errors, all BPMs should read zero since the design orbit is at the center of the vacuum chamber. But this is impossible for a real machine, where orbit distortions always exist. One of the factors causing the orbit distortion is misalignment of quadrupoles. These misalignments accumulate over time due to thermal motion of the magnets and other effects. We have found that it is necessary to examine these effects from time to time. One can reduce the orbit distortion by moving one or more quadrupoles that best correct the orbit distortion. The booster response matrix M_{resp} associated with individual quadrupole movement can be obtained using AT. Then, with the measured orbits x_{BPM} from BPMs, the horizontal movement of one or more quadrupoles dx_{quad} can be solved from the following equation:

$$x_{BPM} = M_{resp} dx_{quad} \qquad (1).$$

As equation (1) is over constrained, $dx_{quad}$is normally not the exact solution. Instead, one can define:

$$\delta x = x_{BPM} - M_{resp} dx_{quad} \qquad (2).$$

to characterize the error of the solution. δx is also the residual orbit distortion if we move the quadrupoles that are solved in equation (1). There are multiple criteria for minimizing the residual orbit distortion, such as the rms distortion, the peak to peak value, or the peak distortion. Also, a small movement is always preferred.

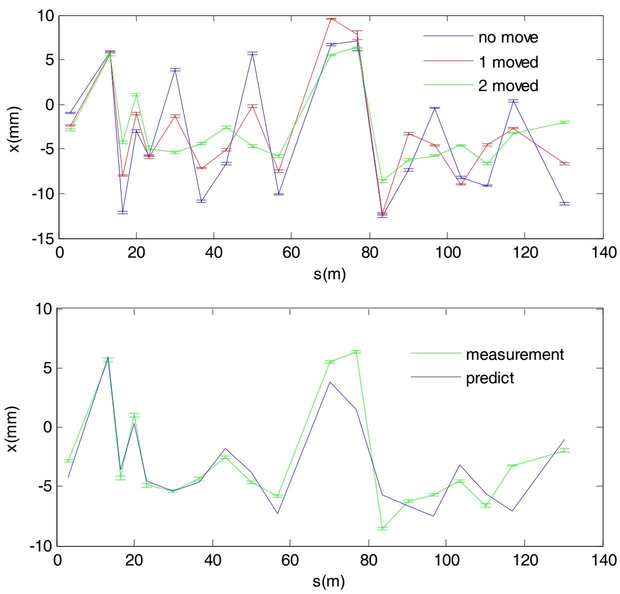

Figure 4: Quads move results

This method was successfully implemented in the booster in 2006 by moving the QF magnet on girder 15. After nearly 5 years, it was necessary to revisit this approach to see if further improvement could be made. Since we are only concerned about the horizontal orbit distortion, only the movement of QFs is necessary. After analyzing the effects of moving one quadrupole, we concluded that it was not quite effective. Thus, moving two QFs was investigated. Eventually, we moved 29QF by 1.04 mm away from the Booster center and 45QF by 1.18 mm toward the Booster center.

The measured residual orbits from 19 booster BPMs after moving one and two quadrupoles are compared with the original orbit in Figure 4 (Top). After moving both 29QF and 45QF, the maximum distortion was reduced from 12.54 mm to 8.57 mm; the peak to peak distortion was reduced from 19.67 mm to 14.94 mm; the rms of the orbit distortion was reduced from 6.96 mm to 4.35 mm. As shown in Fig. 4 (bottom), the final residual orbit distortion agrees very well with the model prediction. We also observed that the effect of the quadruples movements had very little effect on the vertical orbit.

The Booster performance was not significantly improved right after the quads movement. But with some tuning, recently we have seen improved charge capture. Figure 5 shows the "Q meter" signal of the booster, which measures the total charge in booster.

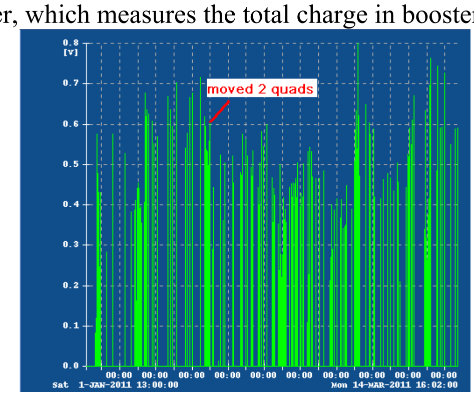

Figure 5: Booster Q meter before and after the move

SUMMARY

Significant efforts have been made to improve the reliability and performance of the injector for SPEAR3. The newly aligned LTB system is much less sensitive to perturbations now, but still requires further work to control non-linearities and improve injection efficiency into the booster.

ACKNOWLEDGEMENTS

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