BOOSTER REQUIREMENTS FOR ADVANCED PHOTON SOURCE 1-NM EMITTANCE UPGRADE LATTICES*

Nicholas S. Sereno†, Michael Borland
Argonne National Laboratory, Argonne, IL 60439, USA

Abstract

In recent years, we have explored various upgrade options for the Advanced Photon Source (APS) storage ring that would provide the user community with higher brightness. Increased brightness would be accomplished by reducing the emittance of the storage ring as well as increasing the stored beam current from 100 mA to 200 mA. Two upgrade lattices were developed [1] that reduce the effective beam emittance to 1 nm from the present 2.7 nm. These lattices have reduced dynamic aperture compared to the present ring lattice, which may require a reduced emittance booster to minimize injection losses. This paper describes injection tracking simulations that explore how high the booster emittance can be and still have no losses at injection for the 1-nm ring upgrade lattices. An alternative booster lattice is presented with reduced emittance compared to the present booster lattice (65 nm).

INTRODUCTION

An APS storage ring (SR) upgrade to lower, 1-nm emittance may require an upgrade to the existing booster synchrotron to maintain high injection efficiency. The envisioned upgrade would typically run the SR at 200-mA stored beam current with a 5-hour lifetime requiring a ≈ 30-second top-up interval [2]. These parameters require the booster to provide ≈ 1.25 nC each top-up shot with $> 90\%$ injection efficiency. In this paper, we evaluate the booster injection efficiency as a function of booster emittance for two different SR 1-nm upgrade lattices [1]. Injection efficiency will be simulated by tracking the injected bunch from the booster and recording the particle losses at apertures after 1000 turns ($\approx \tau_\delta$). The first lattice is symmetric for the whole ring. The second lattice has reduced horizontal beta functions in four symmetric insertion sections around the ring. We conclude with an example of a replacement for the APS booster that reduces the booster emittance well below 65 nm.

APS STORAGE RING 1-NM EMITTANCE UPGRADE LATTICES

Information in this section is derived from [1]. Figures 1 and 2 show the Twiss parameters for the symmetric and low-beta insertion lattices. Both lattices provide room for 8-m-long undulators (compared to 4.8 m at present) and use stronger focusing quadrupoles and combined function dipoles. The low-beta insertion lattice has four insertion sections symmetrically placed around the ring and is intended to accommodate experiments requiring reduced horizontal beam size. Compared to the existing APS lattice, both of these lattices have substantially reduced dynamic aperture. The momentum aperture is $\approx 2-3\%$ for the upgrade lattices. The tracking simulations assume an on-energy beam.

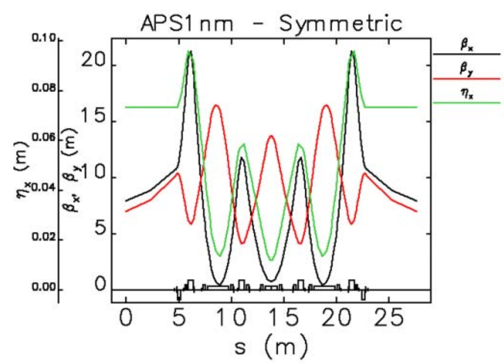

Figure 1: APS 1-nm symmetric lattice Twiss parameters.

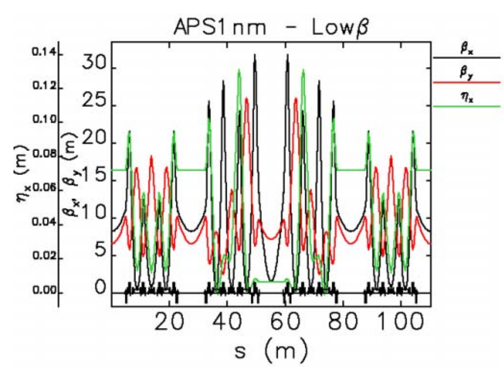

Figure 2: APS low-beta insertion 1-nm lattice Twiss parameters. Four insertions are placed symmetrically around the ring.

APS STORAGE RING UPGRADE LATTICE INJECTION STRAIGHT

Figure 3 shows the injection straight setup for both upgrade lattices. Shown is the placement of four kickers symmetrically about the septum, as well as definitions of various quantities that are relevant to the tracking simulations.

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† sereno@aps.anl.gov

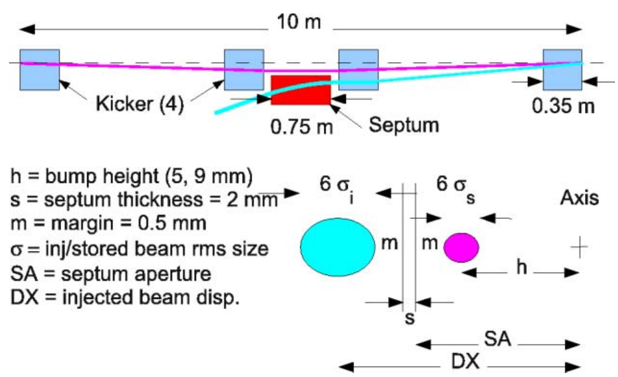

Figure 3: Injection straight section for APS 1-nm upgrade lattices. Shown is placement of kickers and septum as well as definitions of stored and injected beam displacement and septum thickness used in the tracking simulations.

In the tracking simulations, we use two different bump heights h of 5 and 9 mm. The smaller bump height will require lower-voltage kickers but may result in large injection losses, since the injection beam's centroid oscillation amplitude is $\mathrm{DX} - \mathrm{h}$. Locating the kickers and septum in a single straight section eliminates problems with closing the bump due to sextupoles, which is an issue with the present configuration for the APS.

INJECTION TRACKING SIMULATION PARAMETERS

Injection tracking simulations were performed with the program `elegant` [3]. We used common insertion device (ID) and vacuum chamber parameters for all SR sectors for both 1-nm lattices. For the IDs we use 3-cm and 4-mm horizontal and vertical apertures, respectively. For the rest of the vacuum chambers we use 3-cm and 1.5-cm horizontal and vertical apertures, respectively. These are consistent with preliminary magnet designs [4]. For the septum we consider two apertures of 6 and 10 mm, respectively, to accomodate the two symmetric bumps with maximum height of 5 and 9 mm, respectively. The present APS SR kickers can kick the beam to produce a 5-mm bump at 7 GeV [5]. A 9-mm bump may require somewhat longer kickers compared to the present kickers at APS.

The tracking simulations include errors that result in a 5% beta function beat for both lattices [1]. Only one seed was used to generate the errors for each lattice. Correction of the lattices to the level of 5% beta function beating is expected to be achievable with both lattices. We used the present SR kicker waveforms in the simulations and tracked for 1000 turns (about half a damping time) for each lattice, assuming both a matched beam at injection and a mismatched beam at injection. The advantage of a mismatched beam is that it can be brought much closer to the septum, reducing the maximum betatron oscillation at injection. Finally an rf voltage of 10 MV was used to create a stable bucket, and radiation damping and quantum excitation were applied every turn in the simulations.

Figure 4 shows the results for the case of 5% beta function beat for each lattice. Clearly the symmetric lattice is the best in terms of ability to efficiently capture all the injected particles. There is hardly any difference in transmission between the two different bumps up to the present booster lattice emittance (65 nm) for the symmetric lattice. The low-beta insertion lattice shows more losses, particularly for the 5-mm bump. Even for the 9-mm bump there are significant (10%) losses at the present booster lattice emittance of 65 nm.

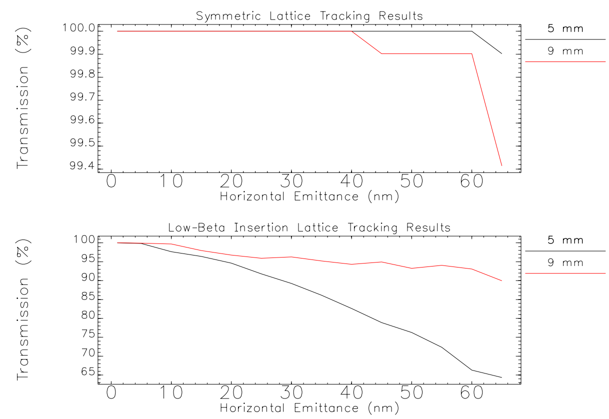

Figure 4: Tracking simulation results showing percent transmission in each lattice after 1000 turns. The different curves in the plots are for the two different bump heights. Both lattice error levels were adjusted so that the beta function beat was 5%.

Figure 5 shows tracking results for the low-beta insertion lattice for the case where the input horizontal beta function was reduced by a factor of five from the matched case. This allowed the injected beam to be brought closer to septum aperture compared to the matched case shown in the bottom plot of Figure 4. For the case of both bump heights, the losses are much reduced due to the ability to bring the beam closer to the septum. One can achieve a similar result by exchanging horizontal and vertical phase-space planes in the transport line from the booster using an optical rotator [6].

BOOSTER LOW-EMITTANCE LATTICE DESIGN

The previous sections showed that it is possible to reduce injection losses for both APS 1-nm upgrade lattices by correcting lattice errors to the 5% beta function beat level, using a large enough bump (i.e., 9 mm) and reducing the horizontal beta function at injection to allow the injected beam to be brought closer to the septum. For the most part, these remedies were required by the lower dynamic aperture low-beta insertion lattice. Since a ring upgrade would involve substantial expense and downtime, we explored an upgrade to the booster to reduce its emittance below 65 nm.

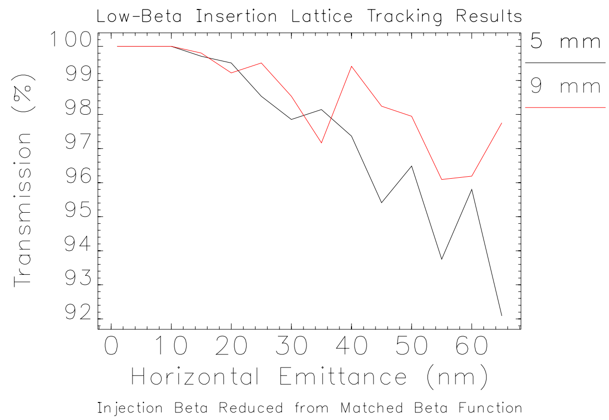

Figure 5: Tracking simulation results showing percent transmission for the low-beta insertion lattice with injection beta function reduced by a factor of five.

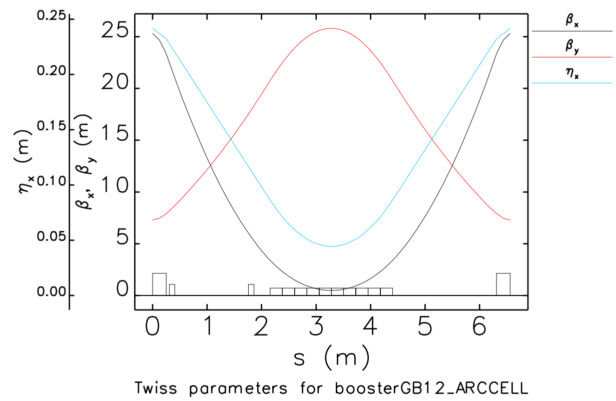

Figure 6: FODO cell for a booster low-emittance lattice upgrade.

The additional capital cost and commissioning time impact for an upgraded booster would need to be factored into the total capital and downtime cost of an APS upgrade.

Figure 6 shows the proposed single-cell FODO lattice design. This FODO cell uses a dipole approximately half the length of the present booster dipoles and includes a gradient to provide vertical focusing. The required dipole gradient at 7 GeV is approximately the same as that envisioned for an APS upgrade that produced the gradient by means of pole face windings [7]. One could also use canted dipole pole pieces to provide the required gradient. The sextupole requirements for chromaticity correction were found to be about a factor of four larger than that for the present lattice, but modest compared to what is required for the APS 1-nm lattice [1]. The natural emittance achieved with this lattice is 9.5 nm at 7 GeV, which would more than accommodate injection into the APS 1-nm lattices considered here. Since this lattice uses higher-field dipoles, the energy loss per turn is roughly twice that of the present booster at 12 MeV at 7 GeV. This additional energy loss would require an upgrade of the present booster rf system, which has a maximum gradient of 11 MV. Alternatively, a more modest decrease in emittance from that of the present booster to the 30-nm level should be acceptable in terms of injection losses for both APS upgrade lattices.

CONCLUSION

Injection tracking simulations were performed for two proposed upgrade lattices for the APS. One lattice is symmetric and has the larger dynamic aperture. The low-beta insertion lattice has smaller dynamic aperture and, not surprisingly, showed larger injection losses. A combination of lattice correction down to the 5% beta function beating level, use of a 9-mm injection bump, and reduction of the horizontal beta function of the injected beam by a factor of five from the matched case resulted in a few-percent injection loss for the low-beta insertion lattice. A new injection section was assumed with all four kickers and the septum located in a single straight section. This avoids bump closure problems that occur when sextupoles are located inside the bump. A low-emittance booster lattice was proposed that would reduce the booster emittance to 9.5 nm from its present 65 nm. This lattice provides much smaller emittance than is actually needed, but appears workable. For example, the chromaticity correction was not difficult.

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