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ATS/STA TRANSFER LINE DESIGN FOR THE ALS UPGRADE PROJECT (ALS-U)*

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Abstract

At the Advanced Light Source Upgrade (ALS-U), an on-axis swap-out injection will be used to replenish depleted bunches in the storage ring with refreshed bunches from a full energy accumulator ring. To fulfill this injection process, two transfer lines are required between the storage ring and the accumulator ring: the accumulator-to-storage-ring (ATS) transfer line and the storage-ring-to-accumulator (STA) transfer line. The design of the ATS/STA transfer lines is a challenging task as they must fit within a tight injection region while also accommodating the storage and accumulator rings at different elevations. Moreover, the ATS/STA design needs to meet both the boundary conditions and optics requirements. In this paper, we will present a design of the ATS/STA transfer lines.

INTRODUCTION

Advanced Light Source Upgrade (ALS-U) is an on-going upgrade project at Lawrence Berkeley National Laboratory which will provide x-ray beams at least 100 times brighter than those of the existing ALS [1]. The upgraded ALS will occupy the same facility as the current ALS, replacing the Triple Bend Achromat storage ring lattice with a compact Nine-Bend Achromat lattice which has a very small natural emittance of about 100 pm-rad. One of the consequences of producing such a small emittance is a small ring dynamic aperture into which an electron beam cannot be injected using a conventional off-axis injection scheme. To overcome this challenge, ALS-U will apply on-axis swap-out injection to exchange bunch trains between the storage ring and a full-energy accumulator ring.

The on-axis swap-out injection scheme was first proposed in paper [2]. At ALS-U, fresh bunches are extracted from the accumulator ring (AR) into the Accumulator To Storage Ring (ATS) transfer line and transported to a fast kicker magnet in the storage ring (SR) to trade places with the spent bunches, which are simultaneously kicked into the Storage Ring To Accumulator (STA) transfer line and then injected into the AR to be replenished. The design of ATS/STA transfer lines is a challenging task as they have to fit within a very tight space meanwhile accommodating different elevations. Moreover, the lattice design of these transfer lines needs to meet optics boundary conditions and minimize size requirements for vacuum-chamber apertures.

In this paper, we will present the designs of ATS/STA transfer lines for ALS-U.

DESIGN REQUIREMENTS

The ATS/STA transfer lines are parts of ALS-U injection system. With the AR and SR placed concentrically and sharing a common 12-fold symmetric layout, the preferred positions for the extraction and injection points in the AR are in the straight 12 and 2 separately, ±30° away from the SR swap-out point where the fast kicker is located. This placement allows to minimizes the ATS and STA transfer-line lengths and allows for a mirror-symmetric design of the two lines as shown in Fig. 1. This defines a first set of design requirements, namely $\Delta\theta_x = 30°$ and $\Delta\theta_y = 0$, for the total horizontal and vertical bending angles through each transfer line. Note that the latter condition is non-trivial, as the SR and AR have different elevations ($\Delta h = 0.635$ m).

A basic timing requirement for the on-axis swap-out injection is that the spent bunches injected into the AR should fall into an rf bucket. The requirement is met if the difference between the combined lengths of the two transfer lines (the path-length from extraction point to injection point through the swap-out kicker point as shown in Fig. 1) and the arc-length separation between extraction and injection points in the AR is an integer multiple $n\lambda_{rf}$ of the wavelength corresponding to the AR/SR rf frequency of 500 MHz. This is the second constraint for the ATS/STA design.

A third set of conditions concerns the matching of the lattice functions (Twiss functions, dispersion functions, and derivatives, in the horizontal and vertical planes). Linear x/y coupling, naturally arising in transfer lines that employ tilted dipoles for vertical bending, is left unconstrained and ideally should be optimized to maximize injection efficiency.

Finally, the ATS/STA need to fit into a very tight injection and extraction region, where there are Booster-to-Accumulator (BTA), SR, and AR are also coexisting. Therefore, the design of the ATS/STA also depends on other systems and need to be optimized to avoid any magnet interference.

ATS DESIGN

Since the ATS and STA lines are mirror symmetric, we only need to focus on one line design (ATS) and the other line (STA) can be obtained by mirror symmetry. The design of the ATS line has proceeded in two steps, first to establish the layout and then the linear optics. Both steps have made extensive use of Multi-Objective Genetic Algorithm (MOGA) [3].

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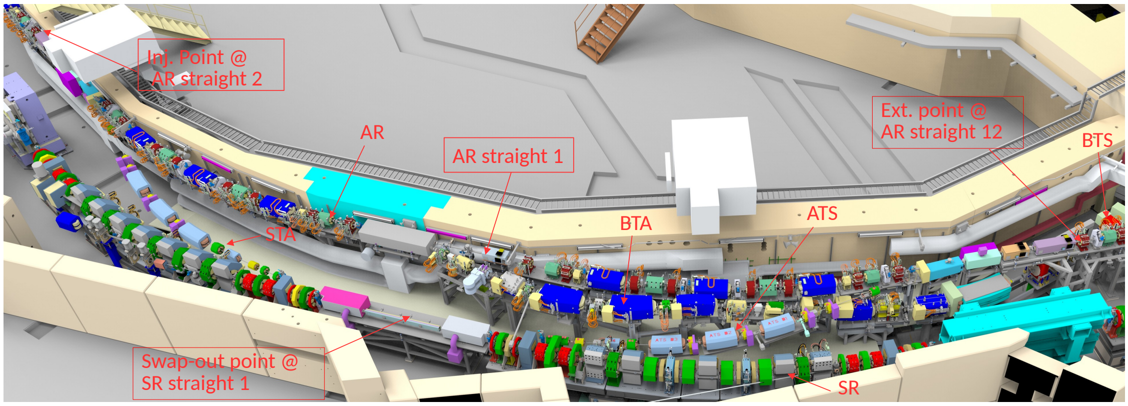


Figure 1: The injection and extraction area of Advanced Light Source Upgrade (ALS-U).

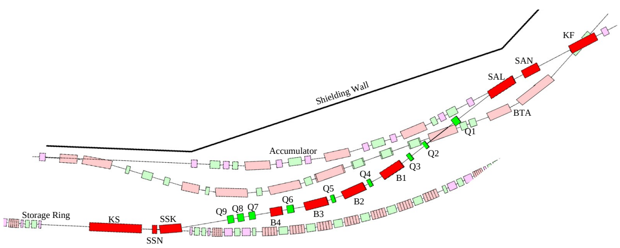
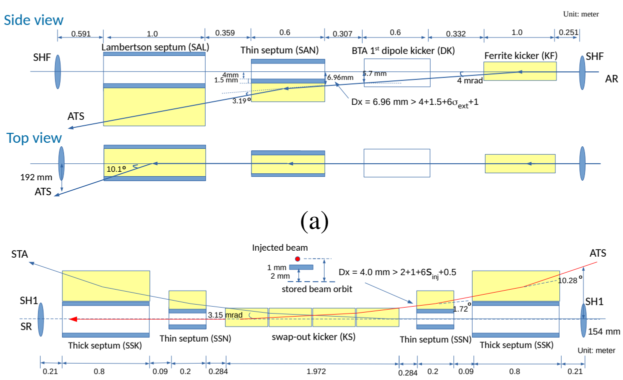


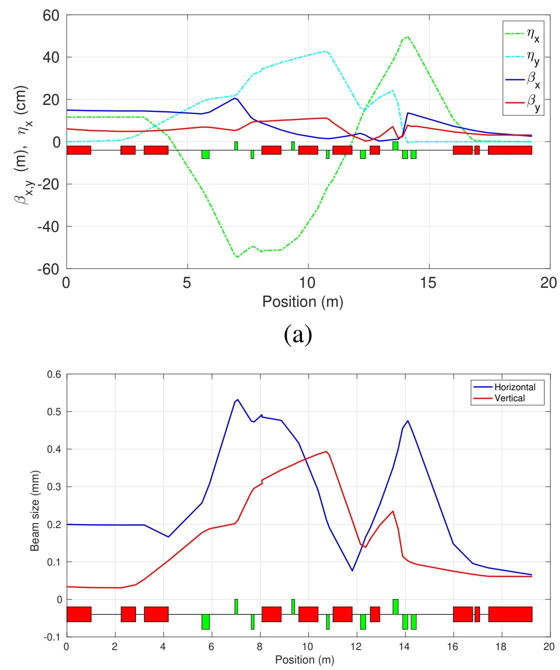
Figure 2: Magnet layout of the ATS transfer line.



(a)

(b)

Figure 3: Schematic layout of (a) AR extraction straight 12 and (b) SR swap-out straight 1.



(a)

(b)

Figure 4: (a) Twiss functions (b) beam size envelopes (1-σ) of the ATS transfer line. 10% coupling in the AR is assumed for the beam size calculation.

Layout Design

The layout of the ATS line is constrained by the injection, extraction and swap-out points and defined by the bending elements through the line. To meet the layout requirements and minimize the potential magnet interference, the beam is extracted vertically from the AR into the ATS line with a ferrite-loaded kicker (KF) followed by a pulsed thin septum (SAN) and then bent horizontally by a DC Lambertson septum magnet (SAL) as shown in Fig. 2. The horizontal bending of about 30°is mainly provided by bending magnets B1, B2, and B3. The bending magnet B4 bends the beam vertically. After B4, the beam lands on the SR plane. The thick (SSK) and thin (SSN) septa provide a total of 12° horizontal bending and bring the beam further closer to the injection straight axis. Finally, the beam is kicked horizontally by the swap-out kicker (KS) into the SR.

The magnet layout for the AR straight 12 and the SR straight 1 are shown in Fig. 3. The spaces are very tight there so that several design iterations have been performed to modify kicker and septa specifications to fit them within these straights and to avoid magnet interference between ATS line and AR/SR. The magnet specifications for all the bending elements in the ATS line are summarized in Table 1.

Optics Matching

Once the layout is established, the linear optics is optimized to match the inject beam Twiss functions to the ones of

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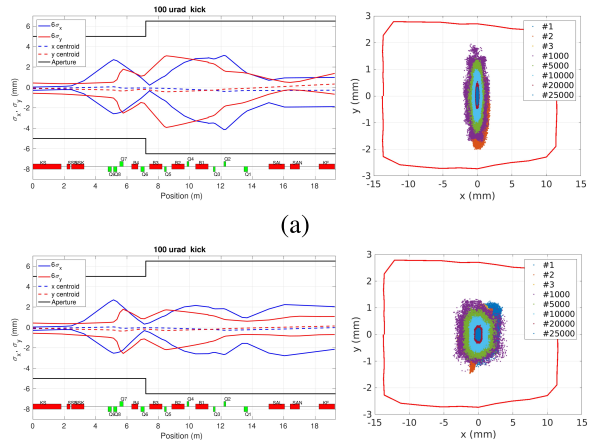
Table 1: Specifications for the ATS Magnets

Name	Len (m)	Ang(D)	K(1/m^2)	Roll(D)
KF	1.00	0.23	-	90
SAN	0.60	3.19	-	90
SAL	1.00	-10.10	-	0
B1	0.80	9.29	-	1.18
B2	0.80	9.29	-	0
B3	0.80	9.29	-	0
B4	0.40	3.81	-	-90
SSK	0.80	10.28	-	0
SSN	0.20	1.72	-	0
KS	1.80	0.18	-	0
Q1	0.312	-	-0.725	0
Q2	0.12	-	4.968	0
Q3	0.12	-	-2.790	0
Q4	0.12	-	0.0874	0
Q5	0.12	-	-4.221	0
Q6	0.217	-	-7.945	78.29
Q7	0.217	-	7.029	62.87
Q8	0.217	-	-7.414	62.87
Q9	0.217	-	-0.522	103.12

the stored beam and to control the x/y coupling as well as to minimize the beam size through the line. 9 quads are inserted into the ATS line for optics optimization. The optimization is carried out using MOGA by tuning the gradient of 9 quads and roll angles of some quads. The maximum transverse rms beam sizes through the transfer are constrained to below 0.6 mm to minimize the vacuum chamber and magnet aperture. The ratio between projected horizontal and vertical beam size is effectively the x/y coupling imparted by the transfer line to the beam, since the vertical emittance at the entrance of the ATS line is only a few percent of the horizontal emittance. During the MOGA run, the ratio between them is optimized to 1, matching the round beam condition of the storage ring.

The Twiss functions and beam size envelope of our baseline lattice are shown in Fig. 4. The dispersion functions at the end of transfer line are zeros in both vertical and horizontal directions, which match the storage ring dispersion functions. The maximum beam size through out the line is about 0.52 mm, and dominated by the contribution of the dispersion function. The beam sizes at the end of the line have be minimized to about 60 µm in both horizontal and vertical direction, which meets the round beam requirement.

The quad specifications are summarized in Table 1. Both the effective length and roll angles of quads have been optimized to standardize the quad design. Q2-Q5 has the same design as well as Q6-Q8, however Q1 and Q9 have an unique design to avoid the magnet interference at the beginning and end of the ATS line. Only Q6-Q9 are rolled to control the x/y coupling.



(a)

(b)

Figure 5: Beam size envelope (left) through the STA Line and beam distributions (right) after injected into the accumulator ring for (a) the mirror symmetric solution and (b) the re-matched solution.

LINEAR OPTICS REMATCHING FOR STA

By design, the STA line is mirror symmetric to the ATS line. However, difference initial beam conditions result in different beam sizes therefore different optics requirements particularly when the SR beam is kicked by a decoherence kicker before extracted into the STA line [4]. The de-coherence kicker is required to dilute the beam charge density to protect the STA line and accumulator ring. The diluted beam has a large beam size and doesn't have Gaussian distribution, therefore marco-particle tracking is needed to study the beam size envelope through the STA line. The tracking result with a 6-sigma initial beam size is shown in Fig. 5. The beam size is about 20-50% larger than the beam in the ATS line. When injected this large beam into the accumulator, it could result in a large beam excursion as shown in Fig. 5. To minimize the beam excursion and improve the injection efficiency, the linear optics of the STA line is rematched. During the rematching, quads gradient are tuned within their design margin and the roll angles are kept the same to the ATS line. The beam size and beam distribution for the rematched solution are show in Fig.5. The beam excursion after injected to the accumulator is smaller than the one for the symmetric solution, improving the injection efficiency.

CONCLUSIONS

In this paper, we present a design of ATS/STA transfer lines for ALS-U injection system. The layout and linear optics of both lines have been optimized to fit within a tight injection and extraction region and to match boundary beam conditions to achieve optimal injection efficiency. The mirror symmetric design of ATS and STA line works. But due to a different initial beam condition, the linear optics of the STA line is slightly re-tuned from the ATS line to re-match the accumulator ring beam condition.

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