ISBN: 978-3-95450-208-0 doi:10.18429/JACoW-IPAC2019-WEPGW111

DESIGN OF BOOSTER-TO-ACCUMULATOR TRANSFER LINE FOR ADVANCED LIGHT SOURCE UPGRADE*

C. Sun†, P. Amstutz, T. Hellert, J.Y. Jung, S.C. Leemann, J. Osborn, M. Placidi, C. Steier, C.A. Swenson, M. Venturini, and W. Wan,
Lawrence Berkeley National Laboratory, Berkeley, CA 94706, USA

Abstract

For the Advanced Light Source Upgrade, an on-axis swap-out injection is applied to exchange bunch trains between the storage ring and the accumulator ring. To replenish the accumulator ring before the swap-out injection, an electron beam from Linac is first injected into the ALS booster to ramp up the energy, and then transported to the accumulator through the Booster-to-Accumulator (BTA) transfer line. The design of the BTA transfer line is a challenging task as it has to fit within a tight space while accommodating the booster and accumulator rings at different elevations. Moreover, the BTA design needs to meet the optics boundary conditions and ideally minimize the size requirements of vacuum-chamber apertures. In this paper, we will present a design option of the BTA transfer line, which meets both space limitations and beam physics requirements.

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 Multi-Bend Achromat lattice which has a very small natural emittance of about 100 nm-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 accumulator ring will be installed in the same storage ring tunnel. It has a similar dynamic aperture as the current ALS storage ring which allows for off-axis injection from the existing ALS booster. To execute the injection process, the Booster-to-Accumulator transfer line (BTA) is needed to transport the beam. The design of the BTA transfer line is a challenging task as it has to fit within a very tight space meanwhile accommodating different elevations. Moreover, the lattice design of this transfer line needs to meet optics boundary conditions and minimize size requirements for vacuum-chamber apertures. In this paper, we will present a design option of the BTA transfer line based on an achromatic vertical dogleg, which meets both the space constraints and beam physics requirements for ALS-U.

DESIGN REQUIREMENTS

The Booster-To-Accumulator (BTA) transfer line transports electron beams from the existing ALS booster to a new accumulator ring. The accumulator ring design is based upon the current ALS Triple-Bend Achromat lattice but with a smaller circumference. It has a similar dynamic aperture as the current ALS, which allows for the off-axis injection from the existing ALS booster. The injection point to the accumulator will be at its first straight section. Due to space limitations, the accumulator will be mounted on the inner shielding wall of the storage ring tunnel at the level of 0.65 meter higher than the ring as shown in Fig. 1. To accommodate this different elevation, the BTA transfer line needs to provide both horizontal and vertical bendings.

To shorten the “dark time” with no user operations during the ALS upgrade, the accumulator ring will be installed and commissioned while the ALS is still in operation. This will require a coexistence of injections to both the accumulator ring and the ALS storage ring. To facilitate this, a “switcher bend” will be installed in the existing Booster-to-Storage ring (BTS) transfer line. This switcher bend will branch out the BTS line to a new BTA line, allowing for switching the injections between the ALS for normal user operation and the accumulator for commissioning. Due to space constraints, this switcher bend will be installed right after the third bending magnet B3 of the BTS line.

As shown in Fig. 1, there are three transfer lines, BTA, ATS (accumulator-to-storage-ring) and STA (storage-ring-to-accumulator) co-existing in the tight injection area. This poses challenges for the transfer line designs. The main challenge for the BTA transfer line design is to avoid magnet interference between the BTA and BTS at the branch-out point and interference between the BTA and accumulator at the injection point. At the injection point, a horizontal injection with pulsed thick and thin septa as shown in Fig. 2 is adopted. These septa are located at the far end of the injection straight to reduce the bending angle requirement for these septa.

The BTA design is constrained by the injection offset and angle at the injection point, which are determined by the injection scheme. Currently, both a nonlinear kicker (NLK) and a two-dipole kicker injections are under consideration [2]. In the following discussion, the NLK injection is assumed and the required injected beam offset and an-

* Work supported by the Director Office of Science of the U.S. Department of Energy under Contract No. DE-AC02-05CH11231
† ccsun@lbl.gov

ISBN: 978-3-95450-208-0 doi:10.18429/JACoW-IPAC2019-WEPGW111

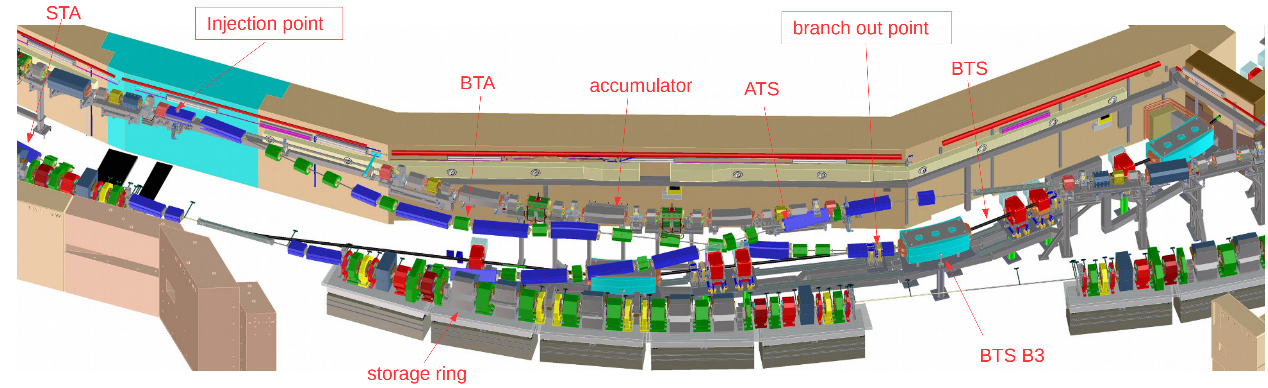


Figure 1: The injection area of Advanced Light Source Upgrade (ALS-U).

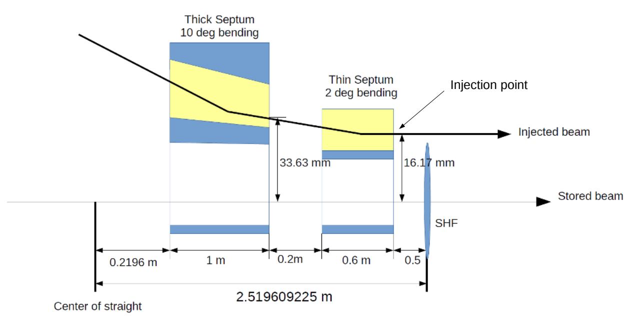


Figure 2: Schematic layout of injection straight for accumulator.

Table 1: Parameters for BTA Bending Magnets

Name	Length (m)	Angle (Deg)	Plane
BTA_B1	1.00	9.0	H
BTA_B2	1.00	8.72	H
BTA_B3	1.00	-8.72	V
BTA_B4	1.10	14.00	V
BTA_B5	1.10	14.00	H
BTA_B6	0.60	7.46	H
SIK	1.00	12.00	H
SIN	0.60	2.03	H

gle are 16.17 mm and 0.4 mrad, respectively. Only minor adjustments are required to accommodate a 2DK injection.

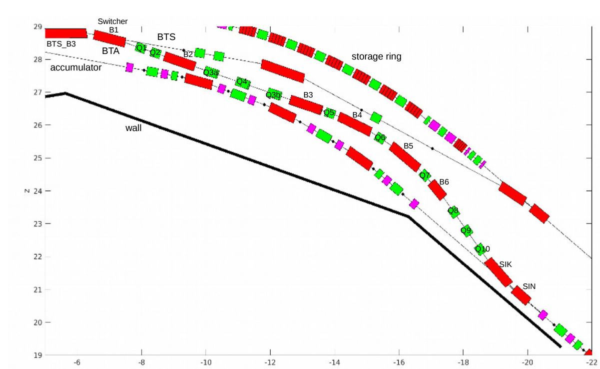


Figure 3: Magnet layout of the BTA transfer line based on an achromatic vertical dogleg design.

VERTICAL DOGLEG DESIGN

As discussed above, the BTA transfer line needs to bend the electron beam both horizontally and vertically. To avoid linear coupling, an achromatic vertical dogleg is adopted in the design. This dogleg consists of a fair of dipole magnets with equal and opposite bending angles. The achromatic condition can be achieved by introducing quadrupoles inside the dogleg to make π phase advance between the two dipoles. This achromatic design will localize the vertical dispersion bump to the dogleg, and eliminates the need for additional vertical dipoles to correct any residual vertical dispersion after the dogleg.

The geometry of the BTA transfer line is defined by the bending angles of dipoles and the lengths of drift spaces along the line. The geometry is also constrained by the injection offset and angle at the injection point. To meet the injection constraints, therefore we need to adjust both bending angles and drift lengths of the transfer line. This can be performed by a matching routine in a global coordinate system. The same coordinate system and its transformation as in MAD [3] are used in this matching routine. Based on the calculated geometry, a 3D visualization tool is developed to lay out elements of the transfer line. With this tool, we can inspect the magnet interference during the geometry matching process without building a CAD model, which will reduce the iterations between the lattice designers and CAD designers.

Figure 3 shows the magnet layout of a BTA transfer line obtained from the matching routine. The switcher bend B1 is located right after the BTS B3 bending magnet. It has only horizontal bending with about 9 degree. After the B1, there is the vertical dogleg defined by the bending magnet B2 and B3. After the dogleg, the beam trajectory is brought to the horizontal plane where the accumulator ring is. Therefore, there are only horizontal bending magnets B4, B5 and B6 required to bend the beam trajectory to the injection

ISBN: 978-3-95450-208-0 doi:10.18429/JACoW-IPAC2019-WEPGW111

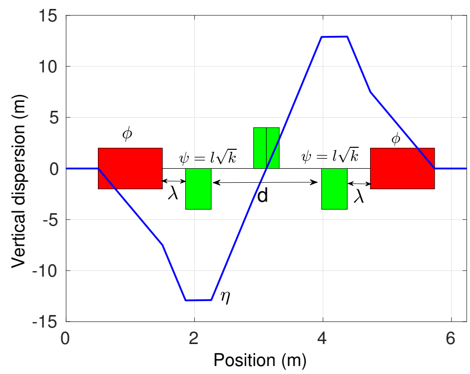


Figure 4: An achromatic dogleg.

straight. In the injection straight, a thick and thin pulsed septa magnets will provide additional horizontal bending to bring the beam trajectory closer to the injection point. This dogleg design not only avoid magnet interference, but also solve magnet support and alignment problems. This design requires stronger bends and quadrupoles strengths but within achievable ranges. The bending magnet parameters are listed in the Table 1.

In our earlier BTA design, rolling some of the dipole magnets was used to provide both horizontal and vertical bendings, thus introducing a strong coupling between the two planes. To remove the coupling, most quads along the line were also tilted. In addition, a vertically bending Lambertson septum magnet (LSM) was used at end of the BTA instead of a horizontally bending pulsed thick septum. This earlier design minimized the magnet strength requirements, but it was eventually abandoned because of magnet interference and magnet support problems.

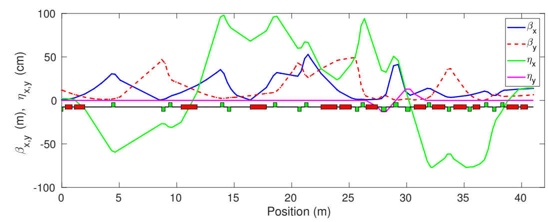
OPTICS MATCHING

After the transfer line geometry is determined, the transfer line optics are tuned to match the accumulator ring optics at the injection point, meanwhile minimizing the beam size along the transfer line. The optics matching is achieved by adjusting the strengths of quadrupoles in the transfer line.

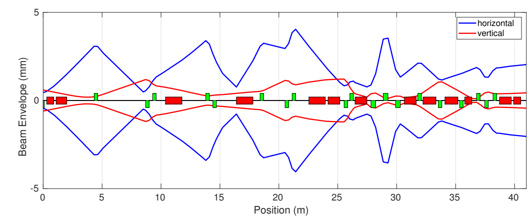
Since the vertical dispersion bump is localized to the dogleg, the vertical achromatic condition for the dogleg can be achieved independently from the horizontal optics matching. To create a vertical achromat, two quadrupoles are inserted into the dogleg symmetrically about the dogleg center as shown in Fig. 4. The achromatic condition is given by the formula [4]

$$\rho \tan\frac{\phi}{2} + \lambda = \frac{1}{k}\frac{d\sqrt{k}\cos(\sqrt{k}l) + 2\sin(\sqrt{k}l)}{d\sqrt{k}\cos(\sqrt{k}l) - 2\sin(\sqrt{k}l)}, \quad (1)$$

where ϕ is the dipole bending angle, k is the quadrupole strength, l is the quadrupole length, and d the drift space between the quadrupoles, and λ is the drift between the bend and quadrupole as shown in Fig. 4. For a given bending angle, the required quadrupole strength will depend on the quadrupole location inside the dogleg. Therefore, there is a minimum setting for the quadrupole strength. Focusing in the horizontal plane can be obtained by adding a third quadrupole of opposite polarity at the symmetry point as shown in Fig. 4.



(a)



(b)

Figure 5: (a) Twiss Parameters (b) beam size envelopes of the BTA transfer line. 300 nm-rad horizontal and 30 nm-rad vertical emittance are used in the beam size calculations.

After the quadrupole settings are determined for the achromatic dogleg, the optics tuning is carried out for the whole transfer line to match the injection point optics meanwhile minimizing the beam size along the transfer line. This is carried out using Multi-Objective Genetic Algorithm (MOGA) [5]. All the quadrupoles in both the existing BTS line and new BTA branch are used as the tuning knobs during optics matching and optimization. There are total 17 quadrupoles, 8 from the BTS line and 9 from the BTA line. The optimization objective is to match the Twiss functions at the injection point. The maximum beta and dispersion functions are constrained during the optimization to minimize the beam size through out the transfer line. Fig. 5.(a) shows the Twiss functions of the BTA transfer line optimized by MOGA. At the end of the transfer line, the Twiss functions of the transfer line match the Twiss functions of the accumulator ring very well. The envelopes of one sigma beam size are shown in Fig. 5.(b), which meet the size requirements of vacuum chamber aperture.

CONCLUSIONS

In this paper, we present a booster-to-accumulator transfer line design based upon an achromatic vertical dogleg for the Advanced Light Source Upgrade (ALS-U). The design decouples both horizontal and vertical motions, and solves the magnet interference problems in a tight space. Optics design of this transfer line also meets its boundary conditions and vacuum chamber size requirements. Fine tuning of this design will be required after we finalize the injection scheme for the ALS-U accumulator.

ISBN: 978-3-95450-208-0 doi:10.18429/JACoW-IPAC2019-WEPGW111

REFERENCES

[1] C. Steier *et al.*, "Status of the conceptual design of ALSU", in *Proc. 9th Int. Particle Accelerator Conf. (IPAC'18),* Vancouver, Canada, Apr.-May 2018, pp. 4134–4137. doi:10.18429/JACoW-IPAC2018-THPMF036

[2] P. Amstutz, M. P. Ehrlichman, T, Hellert, S. C. Leemann, C. Sun, C. Steier, and M. Venturini, *Accumulator-Ring injection options and beam-physics studies*, Tech. Note ALSU-AP-TN-2019-03.

[3] L. Deniau, H. Grote, G. Roy, F Schmidt. *The MAD-X Program-Version 5.04.01, User's Reference Manual.*

[4] K. Steffen, CERN-85-19-V-1, CAS-CERN Accelerator School: *General Accelerator Physics*, vol.1, 1985, p. 55.

[5] K. Deb, A. Pratap, S. Agarwal and T. Meyarivan, *IEEE Transactions On Evolutionary Computation*, vol. 6, no. 2, 2002.