ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-TUPMF017

TRANSPORT LINE DESIGN AND INJECTION CONFIGURATION OPTIMIZATION FOR THE ADVANCED PHOTON SOURCE UPGRADE*

A. Xiao, M. Borland, ANL, Argonne, IL 60439, USA

Abstract

On-axis swap-out injection was chosen for the Advanced Photon Source Upgrade (APS-U) to allow pushing the beam emittance to an extremely low value. The injection section configuration was optimized within a multi-dimensional parameter space and made consistent with up-to-date technical developments. The booster-to-storage ring (BTS) transport line was designed to bring the electron beam from the existing Booster to the new storage ring (SR). Due to various limitations, this new BTS line is twisted both horizontally and vertically when approaching the injection point, which introduces challenges in both geometrical and optical matching. This paper presents our simple solution to these issues. The coupling effect caused by the twisted BTS line is also discussed.

INTRODUCTION

The APS is considering a major update targeting a natural emittance of 42 pm at 6 GeV [1]. One of the consequences of pushing beam emittance to such an low value is that the achievable dynamic aperture becomes extremely small compared to operating 3rd-generation light sources due to the inherently strong nonlinear effects. As a result, the traditional off-axis injection scheme can not be used. To overcome this challenge, APS-U will use on-axis swap-out injection to inject full-charge bunches from booster directly, while the most-depeleted bunch will be sent to the swap-out dump. The extraction/injection scheme is shown in Fig. 1.

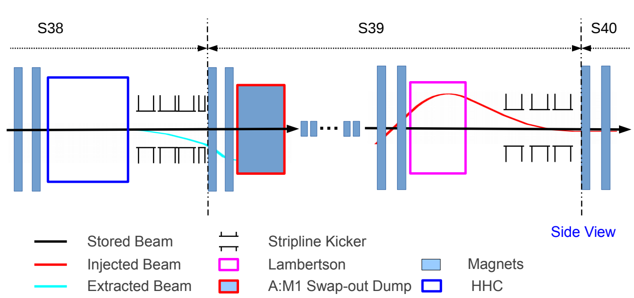

Figure 1: Schematic plot of extraction/injection region.

The most challenging part for this on-axis swap-out injection scheme is the injection section configuration, which puts strict requirements on the stripline kicker, septum magnet, and high voltage pulser due to limited available straight section space and short bunch spacing when operating in the 324-bunch fill pattern.

* Work supported by the U.S. Department of Energy, Office of Science, Office of Basic Energy Sciences, under Contract No. DE-AC02-06CH11357.

To relax the requirements on the stripline kicker and high voltage pulsers, vertical injection was selected. Consequently, the BTS line needs to be twisted so as to provide a clear path for the injected beam to go through the SR magnets. The geometry of BTS line needs to be re-matched both horizontally and vertically within the existing tunnel, which makes it challenging. Another challenge exists for optical matching due to a large optical function changes at the injection point compared with current APS ring, as well as strong leakage field from the Q1 magnet which both injected beam and stored beam must transit.

This paper first summarizes the results on injection section configuration optimization. We then describe the process of matching the BTS geometry. Finally, a preliminary optical design result is presented.

INJECTION SECTION OPTIMIZATION

The most challenging part for the on-axis swap-out injection scheme is the injection section configuration which contains two key types of elements:

- Septum – provides a horizontal bend to the injected beam. At the downstream end of septum, the injected beam trajectory merges with the stored beam orbit horizontally, but with a vertical displacement. The septum is tilted slightly to bend injected beam vertically, allowing it to pass through the midplane opening slot of two nearby storage ring quadrupole magnets.
- Fast stripline kickers – provide vertical deflection to the injected beam. At the downstream end of the stripline kickers, the injected beam orbit merges to the stored beam orbit vertically, thus completing on-axis injection.

The minimum horizontal separation (ΔX) between injected and stored beam, which allows putting the last BTS line

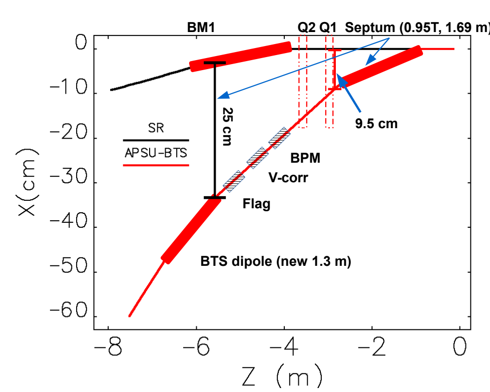

Figure 2: Stored and injected beam orbit and magnet layout around injection section.

ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-TUPMF017

dipole (CB1) next to the SR dipole (BM1), is determined by the magnets' engineering design [2]. It is also desirable to put CB1 as close as possible to the injection point. Thus, the minimum beam separation is set to 25-cm at $Z = -5.5$m. Some possible septum parameters (combinations of septum length and strength) are listed in Table1.

Table 1: Possible Septum Parameters for 25-cm Beam Separation at $Z = -5.5$m

Septum Strength	Septum Length
1.0 Tm/m	1.62 m
0.95 Tm/m	1.69 m
0.9 Tm/m	1.76 m

A conceptual plot of injected and stored beam vertical orbit along the injection straight is shown in Fig. 3. Assuming the injected beam vertical emittance is 20-nm, then $M1$ is the clearing distance from $+3\sigma_y$ of the injected beam envelop to the top blade of stripline kicker, and $M2$ is the clearing distance from the $-3\sigma_y$ of the injected beam envelop to the bottom of injected beam chamber at the downstream end of septum. The $M1$ and $M2$ values depend on multiple parameters:

- Septum length (strength) – since both septum and stripline kickers share the same straight section, with other parameters fixed, a longer septum will give a smaller $M2$ as the downstream end of septum shifts to the right side as shown in Fig. 3.
- Blade (pulser) voltage – Higher voltage give a stronger vertical kick. With other parameters fixed, higher blade voltage reduces $M1$, while increasing $M2$.
- Stripline gap – Smaller gap gives stronger vertical kick. With other parameters fixed, smaller stripline gap reduces $M1$, while increasing $M2$.
- Stripline length – longer stripline length gives more vertical kick. With other parameters fixed, longer stripline length reduces $M1$, while increase $M2$.

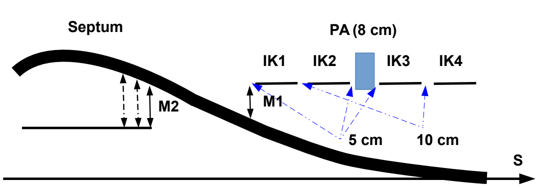

Figure 3: Conceptual plot of vertical beam orbit along injection straight.

These four parameters were scanned over possible engineering ranges in order to find the optimal values. An example result at 18 kV gap voltage with a 0.9 T septum strength is show in Fig. 4. The crossing points shown in Fig. 4 indicates that at that particular parameter set, beam clearances at the stripline ($M1$) and at the septum ($M2$) are equal, which is optimal. Connecting all cross points from one particular gap voltage and septum strength together, we obtain the results

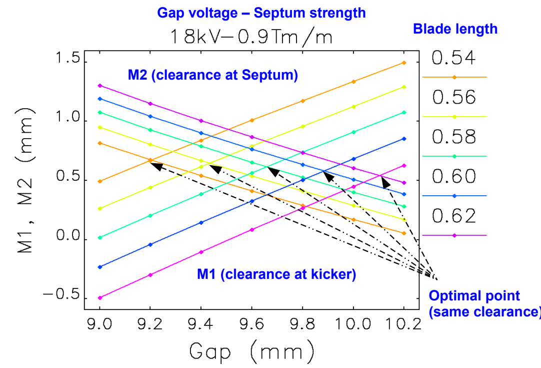

Figure 4: Calculated beam clearance $M1$ (lines have positive slope) and $M2$ (lines have negative slope) for stripline gap voltage of 18 kV and septum strength of 0.9 T vs stripline length (legend) and stripline gap (x-axis). Crossing points are optimal.

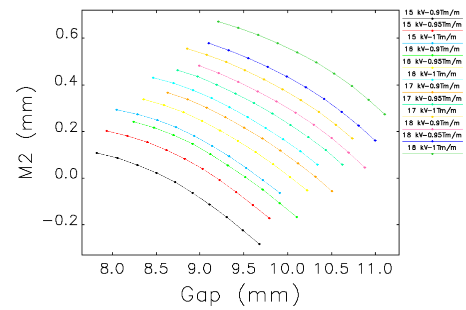

Figure 5: Connected optimal points (crossing points as shown in Fig. 4) from all simulated cases (legend). Stripline length is 0.54 m to 0.72 m in 0.02 m steps from left to right.

shown in Fig. 5. Based on optimization results, an injection scheme with three stripline kickers was chosen for the baseline design. Optimized parameters are: $L = 0.72$ m, 9-mm gap, ±18-kV blade voltage for stripline, and 0.95 T, 1.78 m for septum.

GEOMETRY MATCH OF APS-U BTS LINE

The current BTS line has three sections (A,B,C), see Fig. 6, where section A is inside the Booster tunnel, while most of the section B (starts from BQ1) and all of section C are inside the SR tunnel. To avoid any major change of the infrastructure, the new BTS line design preserves all magnet locations up to the first magnet (BQ1) inside the SR tunnel. The B section dipoles (BB1 and BB2 for current APS, BB1 only for APS-U) strength and location will be changed plus an additional dipole (CB1), where CB1's strength is a variable but its location is fixed from previous step on injection section optimization, to make the geometry match. Using the floor-coordinate fitting features of `elegant` [3], we adjusted the tilt angles of BB1 and CB1 to match both horizontal and vertical geometry simultaneously. The geometry matching results are shown in Fig. 7. Due to the non-commutative property of coordinate system rotation, there will be a small non vanishing rotation angle, i.e. $\psi \neq 0$

ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-TUPMF017

at the end. This will be treated as a systematic error in future tracking simulation and is the source of $x - y$ coupling.

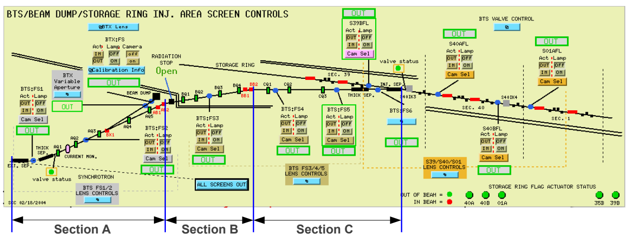

Figure 6: Current APS BTS line configuration.

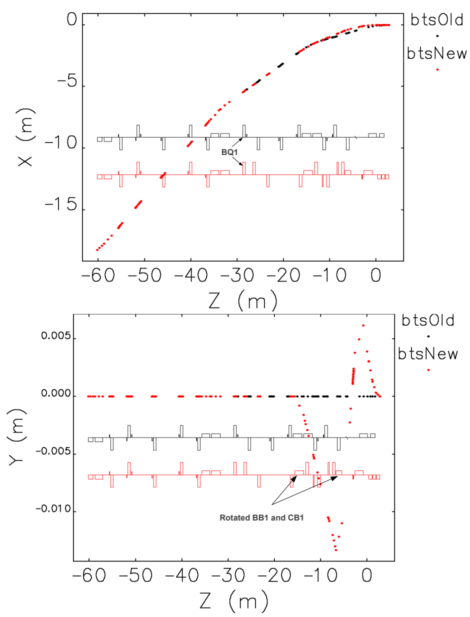

Figure 7: Geometry matching results of BTS line. (upper) - horizontal; (lower) - vertical.

OPTICAL MATCH OF APS-U BTS LINE

Following geometry matching, the BTS line optics was matched to the stored beam at the injection point. It started with a rough matching of section C in a backwards direction to obtain zero dispersion at the end (entrance of section C in injected beam direction) and reasonable beta functions over the entire section. Then section A was slightly adjusted to obtain zero dispersion at the end also. Section B is matched thereafter to connect section A and C together. At the end, section B and C are optimized together to obtain a complete optical match at the injection point. At this stage, two weak skew Quads are also added to the section C to cancel the vertical dispersion at the injection point. Matching results all shown in Fig. 8. All major magnets strength and location are summarized in Table2. Except BQ1, all section B and C magnets need to be relocated. Three new magnets (CB1, CSQ1 and CSQ2) are required. One BTS dipole (BB1) need to be tested to see if it can be operated at a ~20% higher value than current specification, if not, another new dipole magnet is required.

Table 2: BTS Line Main Magnet Parameters

Name	Length m	K1(m^{-2}) θ(rad)	New Magnet	New Location
AQ1	0.6	-0.59	No	No
AQ2	0.6	0.60	No	No
AQ3	0.6	-0.44	No	No
AQ4	0.6	0.56	No	No
AQ5	0.6	-0.33	No	No
AB1	1.938	0.077	No	No
AB2	1.938	0.077	No	No
BQ1	0.6	0.41	No	No
BQ2	0.6	-0.20	No	Yes
BQ3	0.6	-0.22	No	Yes
BQ4	0.6	0.54	No	Yes
BB1	1.938	0.108	???	Yes
CB1	1.3	0.071	Yes	Yes
CQ1	0.6	0.92	No	Yes
CQ2	0.6	-0.94	No	Yes
CQ3	0.6	0.85	No	Yes
CSQ1	0.2	-0.15	Yes	Yes
CSQ2	0.2	0.04	Yes	Yes

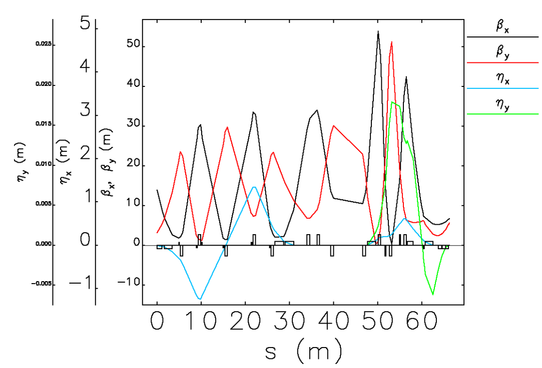

Figure 8: Optical function for the new BTS line.

SUMMARY

On-axis swap-out injection scheme was selected for the APS-U new ring design. The injection section was optimized based on available technology and balancing of risks. A simplified geometry matching of new BTS line was done by tilting the dipole magnet. Finally, a preliminary optical design was performed, showing that the required changes to the existing BTS line are fairly moderate.

REFERENCES

[1] M. Borland *et al.*, in *Proc. of NAPAC 2016*, p. 877–880 (2016).

[2] M. Abliz *et al.*, private communication.

[3] M. Borland, Technical Note ANL/APS LS-287, Advanced Photon Source (2000).