ISBN: 978-3-95450-168-7 doi:10.18429/JACoW-IPAC2015-TUPMA056

ANALYSIS OF POSSIBLE BEAM LOSSES IN THE NSLS II BSR TRANSFER LINE

S. Seletskiy#, R. Fliller, W. Guo, S. Kramer, Y. Li, B. Podobedov, T. Shaftan, B. Wahl, F. Willeke, BNL, Upton, NY 11973, USA

Abstract

The NSLS-II accelerators are installed within 0.8 – 1 m thick radiation shielding walls. The safety considerations require attenuating the radiation generated from possible electron beam losses to a level of <0.5mrem/h at the outer surface of the bulk shield walls. Any operational losses greater than specified level shall be addressed by installing supplemental shielding near the loss point. In this paper we discuss simulation studies that identified potential beam loss locations. Results of these studies were used for identification of imposed radiation risks and for specification of the supplemental shielding design necessary to mitigate those risks.

INTRODUCTION

The NSLS-II accelerator complex [1] consists of 200 MeV linac, the Booster accelerating beam to 3 GeV, the 3 GeV Storage Ring (SR) and the two transfer beamlines – Linac to Booster transfer line and Booster to Storage Ring (BSR) transfer line. Missteering of the e-beam that can be caused by operator's mistake or by magnet failure can result in unacceptable radiation levels on experimental floor. Design of personnel radiation protection shielding [2] at NSLS-II relies on detailed analysis of physically possible steering errors in various parts of accelerator. In this paper we describe such analysis for the Booster to Storage Ring transfer line. An inventorial description of the beam steering considerations in the BSR and of their effect on radiation safety can be found in [3].

BEAMLINE DESCRIPTION

Below we consider three beamlines (Fig. 1): the Booster extraction section (ES), the Booster to Storage Ring transfer line phase 1 (BSR-P1) and the BSR transfer line phase 2 (BSR-P2).

The Booster ES consists of four slow bumps forming local closed 4-bump BU1, BU2, BU3 and BU4, four fast kickers K1, K2, K3 and K4, pulsed septum magnet SP1 and a DC septum magnet SP2. These magnets are utilized for the extraction of the beam from the Booster into the BSR line. All four bumps (B1-4) are powered in series. Pairs of kickers K1-2 and K3-4 are powered in series as well.

The BSR-P1 line consists of five quadrupoles (Q1, Q2, Q3, Q1BD and Q2BD) and one bending magnet (B1). These magnets transport beam to the beam dump when bending magnet B2 is turned off.

The BSR-P2 includes Q1-Q3 and B1 as well as quadrupoles Q4-Q14 and bends B2-B4. These magnets transport beam to the Storage Ring. Injection into the Storage Ring is performed with SP3 and IS, which are the DC and pulsed SR injection septa respectively. The SR injection region is analysed for in [4, 5].

Detailed description of each of the BTS beamlines elements is given in [3].

BEAM STEERING ANALYSIS IN ES

Although the ES magnets are supposed to be used only at extraction energy of 3 GeV technically they can fire at any point of Booster ramp. Since these magnets are powered in series there are three scenarios to consider: either kickers K1 and K2 fire, or K3 and K4 fire, or four bumps BU1-4 fire. With the approach to the analysis described farther in this paper and under provision that bumps BU2-4 are treated independently from bump BU1 (see below) the three described scenarios cover all possible local beam losses that can happen under any feasible ES settings.

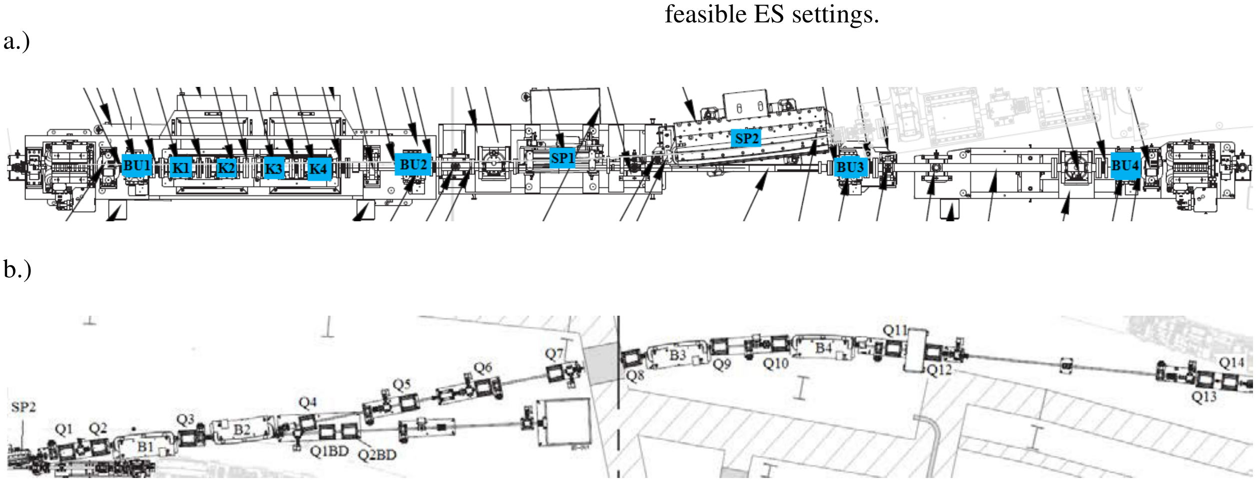

Figure 1: The Booster extraction section (a) and the Booster to storage ring transfer lines phase 1 and phase 2 (b).

#seletskiy@bnl.gov

ISBN: 978-3-95450-168-7 doi:10.18429/JACoW-IPAC2015-TUPMA056

To explore various scenarios of beam steering we performed beam tracking with a set of dedicated Python-based codes. These codes utilize a following general beam tracking algorithm.

We start with transverse phase space populated with beam centroids (defined below) at the entrance of the first magnet. Next, we track such phase space at particular energy either through the “chain” of magnets (for magnets powered in series) or through an individual magnet varying each magnet settings in their full range.

ES Beam Steering at Low Energy

Since at the lowest possible Booster energy (150 MeV) electron beam might be a freshly injected one rather than the stored one, the proper method of defining the beam centroids phase space at the entrance of the magnets is to define it by the acceptance of the respective upstream drift. This technique, although it results in overestimating the lost beam angles provides a bullet-proof guarantee that all possible beams entering the magnet are considered. The described method (below we will refer to it as a “transfer line approach”) is illustrated in Fig. 2.

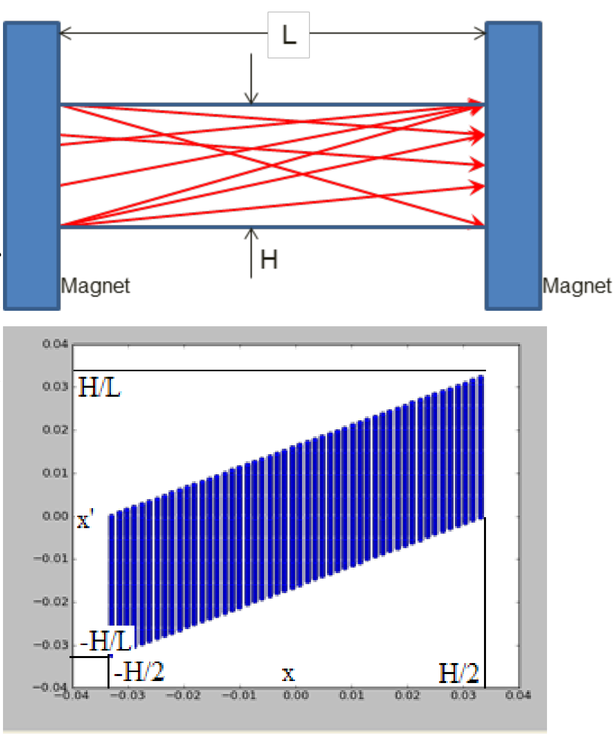

Figure 2: The picture on top schematically shows the beam centroids (red) originating at the upstream magnet and filling the drift upstream of the first magnet to be used in tracking. The bottom plot shows the horizontal phase space at the entrance of this magnet defined by geometry of the upstream drift.

Starting with the beam centroids phase space described above we track each beam centroid through the first “chained” magnet. We stop tracking the beam if it hits the magnet yoke and record the angle at which such beam was “lost”. Here, by the lost beam we mean that it is not a bright electron beam traveling towards the tunnel wall anymore.

Next, we record the beam angle at the exit of the magnet and track the beam through the drift to the next chained magnet. If the beam makes it to the entrance of the next magnet without hitting the vacuum chamber then the described tracking procedure is repeated for this magnet. This routine is continued until the exit of the last chained magnet is reached. Fig. 3 illustrates this procedure. The described tracking is performed for each beam centroid (we fill the initial phase space with 2500 centroids). The magnets fields are scanned in their full range.

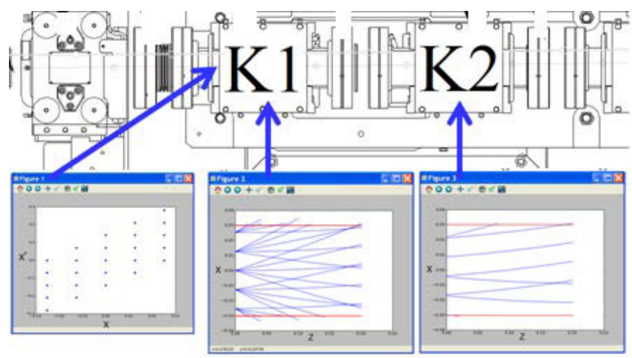

Figure 3: The left plot shows the beam centroids phase space at the entrance of K1, which is defined by the geometry of upstream drift. For illustration purposes the phase space is filled with 25 beam centroids only (actual tracking uses 2500 centroids). The central plot shows beams tracked through K1. The right plot shows beams (which survived the K1 and K1-K2 drift) tracked through K2. Red lines represent magnet yoke. The tracking is shown for maximum K1-2 current only.

Finally the maximum angles of the beams lost inside and exiting each magnet are determined. Found angles are used for the analysis of possible radiation losses and for the design of respective radiation protection shielding [3].

In the Booster ES we do the tracking for the following chains of magnets: K1-K2, K3-K4 and BU2-BU3-BU4. The BU1 is treated as a stand-alone magnet since the simple correlation between phase space at BU1 exit and BU2 entrance is broken due to the presence of kickers in between BU1 and BU2 (see Fig. 1).

ES Beam Steering at High Energy

At high energy (we consider 2 GeV and 3 GeV beam) the tracking procedure is almost identical to the one described above. The only difference is in the generation of the initial phase space of the beam centroids.

At high energy the electron beam is stored in the Booster. This shrinks the phase space available to the beam centroids at the entrances of ES magnets significantly. Indeed, prior to the moment the fast magnets are turned on the stored beam in the ES shall be within the acceptance of 8.15 m long extraction drift.

ISBN: 978-3-95450-168-7 doi:10.18429/JACoW-IPAC2015-TUPMA056

Although ES bumps are slow in comparison to beam revolution time the phase space defined by the acceptance of the long extraction drift can be immediately used at BU1 entrance since the four bumps are designed to create only a localized distortion of the stored beam trajectory. At the entrance to K1 one can use the phase space described above with the limit of positive horizontal angle increased by the maximum BU1 kick. Similarly, for K3 the respective phase space limits shall be increased by maximum summed kicks of BU1, K1 and K2, and for BU2 entrance the phase space limit must be increased by the sum of maximum kicks of BU1 and K1-K4.

Such approach significantly reduces the initial phase space available to beam centroids as compared to transfer line approach, while covering the full possible range of beam steering.

BEAM STEERING ANALYSIS IN BSR

The beam tracking in both BSR-P1 and BSR-P2 is similar to the one used for the Booster ES. Fig. 4 illustrates the tracking procedure using the bend B1 as an example.

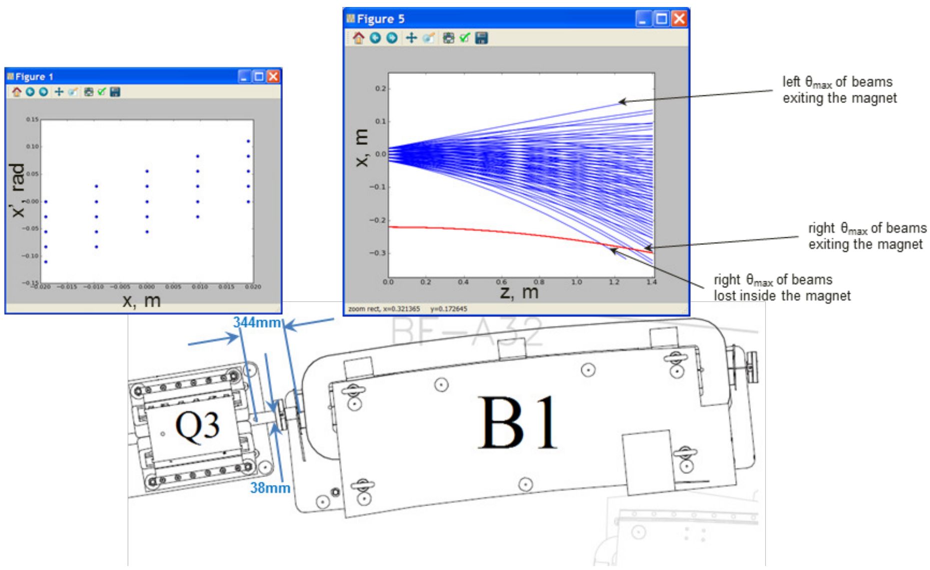

Figure 4: Beam tracking in BSR (B1 example). The phase space available to the beam centroids at the entrance of B1 (left plot) is defined by the geometric acceptance of Q3-B1 drift. The phase space is filled with 25 beam centroids (for the clarity of the picture we reduced the number of beam centroid usually used in tracking by a factor of 100). Each of these beams is tracked through B1 (right plot) at its minimum, nominal and maximum settings. The red line on the right plot represents B1 yoke.

To determine the beam centroids phase space at each magnet entrance we adopt the transfer line approach. Next, we track each beam centroid through the magnet varying its field in the full range. Finally, we determine the maximum angles of the beams lost inside the magnet as well as the maximum angles of the beams exiting the magnet both to the left and to the right of the direction of beam motion.

CONCLUSIONS

In this paper we presented the studies of possible beam missteering in NSLS-II BSR transfer line. We applied the dedicated tracking codes to studying various cases of possible beam losses. The found maximum angles, at which the beam can be lost in each transfer line magnet, were used for analysis of possible radiation losses in the BSR and for design of the respective radiation shielding. Commissioning and operation of NSLS-II gave an ultimate proof of the adequacy of the resulting radiation shielding.

ACKNOWLEDGEMENTS

We are grateful for support from the NSLS-II. We obtained a lot of help and advice from M. Breitfeller. This work is supported in part by the U.S. Department of Energy (DOE) under contract No. DE-AC02-98CH1-886.

REFERENCES

[1] NSLS-II CDR, 2006.
[2] S. Kramer, “Shielding Specification and Design Document for the BSR-P2 and Storage Ring” LT-C-ASD-RSI-SR-001, 2013.
[3] S. Seletskiy, “Analysis of localized beam losses in the Booster extraction straight section and the Booster to Storage Ring transfer line” BNL-101037-2013-IR, 2013.
[4] Y. Li, S. Seletskiy, “Analysis of Mis-Steered Electron Beam in the NSLS-II Storage Ring” NSLS-II Tech. Note. 122, 2013.
[5] S. Seletskiy et al., TUPMA055, IPAC15, 2015.