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ENERGY INTERLOCK IN THE NSLS II BOOSTER TO STORAGE RING TRANSFER LINE

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Abstract

Under normal operational conditions in NSLS-II the energy of the beam extracted from the Booster and transferred to and injected into the Storage Ring (SR) is 3 GeV. It was determined that for the commissioning purposes energy range of the beam reaching the SR is allowed to be 2 GeV - 3.15 GeV. While the upper limit of the beam energy is defined by the maximum possible settings of Booster dipoles at the top of the ramp, the lower energy limit has to be provided by magnet interlocks. The constraints of time and resources do not allow providing dynamic interlocks of the Booster dipoles for commissioning stage of NSLS-II. In this paper we find a feasible solution for the static interlock of magnets in the Booster to SR transfer line (BSR) which creates a required "energy filter".

INTRODUCTION

The NSLS-II accelerator complex [1] consists of 200 MeV linac, the Booster accelerating beam to 3 GeV and the 3 GeV storage ring. Design of personnel radiation protection shielding [2, 3] relies on limiting the energy of beam reaching the SR within some reasonable range. A decision was made [4] to set the lower boundary of the energy range to 2 GeV. The upper boundary of 3.15 GeV is defined by maximum energy that the Booster can achieve. While eventually the operational energy interlock (EI) will be provided by setting limits on Booster dipoles, the commissioning of the storage ring required a simple and quick EI solution. Below we will describe the energy interlock in the Booster to storage ring transfer line that was designed, implemented and is currently used for SR commissioning. An inventorial description of this EI and of its effect on radiation safety considerations can be found in [5-7].

BSR DESCRIPTION

The Booster to Storage Ring transfer line includes two beamlines BSR-P1 (phase 1) and BSR-P2 (phase 2).

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-P1 also includes the Booster pulsed extraction septum (SP1), and DC extraction septum (SP2).

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 BTS layout is shown in Fig. 1. Detailed description of each of the BTS beamlines elements is given in [8].

BSR ENERGY INTERLOCK

Requirements to the BSR EI are straightforward. It has to be located as close to the beginning of the BSR as possible and its physical realization has to be as simple as possible. It is undesirable to interlock the quads from accelerator physics point of view. The first DC bend in the BSR is SP2. Yet, since it has a nonstandard power supply, interlocking this dipole is questionable from engineering point of view. These considerations leave one with bends B1 and B2 as interlock devices of choice. These two bends are located at the very beginning of the BSR. They are close to each other and there is just one quad in between them. Finally, adding a few percent interlock to B1 or B2 power supplies is a trivial engineering task.

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

We start with the beam centroids phase space defined by the geometric acceptance of the drift upstream of SP1. The initial phase space is populated with 2500 beam centroids. It was checked that increasing the number of centroids does not affect final result. Such phase space is schematically shown in Fig. 2.

Next, we track this phase space at particular energy through the beamline down to the entrance of the dipole of interest varying each magnet settings in their full range, i.e. we perform a cascaded parameter scan [9]. In studies described below each magnet goes through 10 settings spanning the range of possible magnet values. It was determined that the chosen number of magnet settings is ample since 10 resulting beam centroids phase spaces at magnet exit overlap well enough to exclude the possibility of missing any centroids.

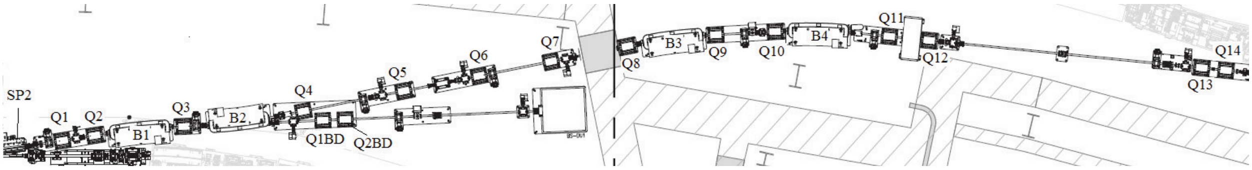

Figure 1: The Booster to storage ring transfer line.

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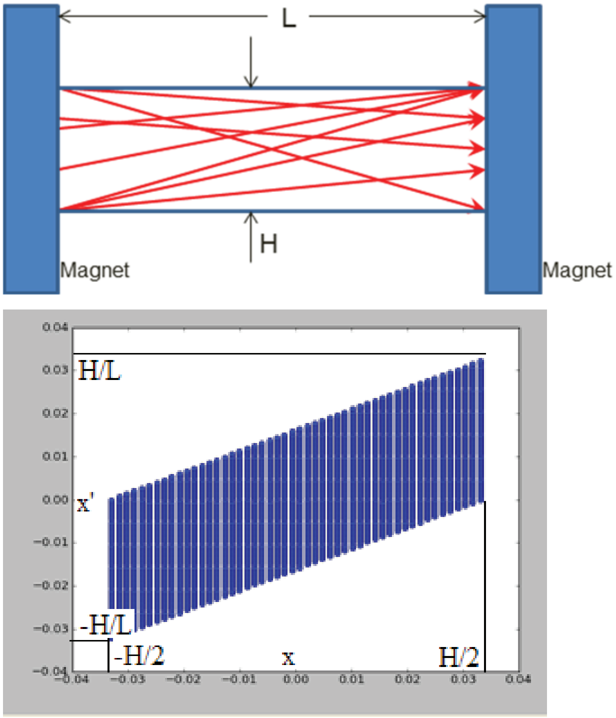

Figure 2: The picture on top schematically shows the beam centroids (red) originating at the upstream magnet and filling the drift upstream of SP1. The bottom plot shows the phase space at the entrance of SP1 determined by geometry of the upstream drift.

While tracking, the vacuum chamber dimensions in both magnets and drifts are taken into account, and the beam centroid hitting the chamber is considered to be lost. At the downstream end of each beamline element the phase space is repopulated, to exclude exponential growth of the number of beam centroids and to ensure that the number of beam centroids stays approximately the same throughout the whole tracking routine. The method of repopulating the phase space, a so-called "phase space sand moulding", is schematically shown in Fig. 3. In our studies the number of beam centroids in the "sandbox" was 2500. It was checked that increasing this number did not affect final results.

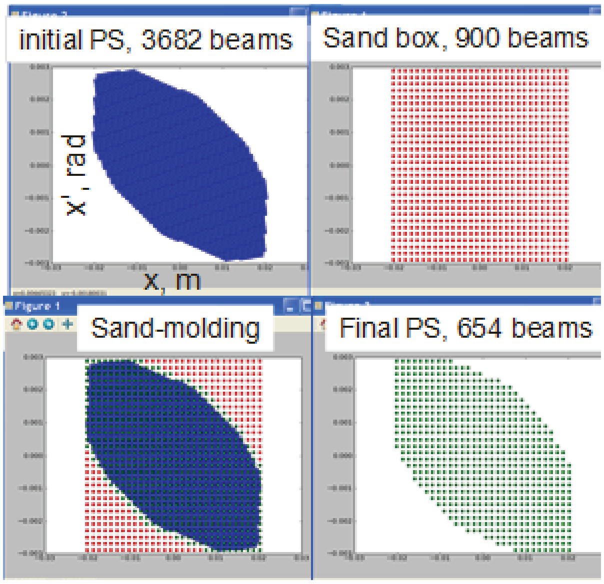

Figure 3: In sand-moulding technique the repopulated phase space is obtained by "imprinting" the original phase space on the "sand box" of beam centroids.

As a next step, we study various cases of possible interlocks by following the tracking procedure described above.

For example, to study the case of B1 and B2 interlocked within +-2% of their nominal 3 GeV values we first track the phase space of possible 2 GeV beam centroids through the beamline upstream of B2 with B1 fixed within +-2% of its nominal value and all other magnets varied in their full range of strengths at 2 GeV.

Next, we track obtained phase space through B2 interlocked at its nominal 3 GeV setting and compare the phase space at B2 exit with acceptance of the rest of the BSR. The acceptance of B2-SR beamline is obtained from backtracking of the phase space of all possible beam centroids in SP3-IS drift to the exit of B2.

Results of this study are presented in Fig. 4.

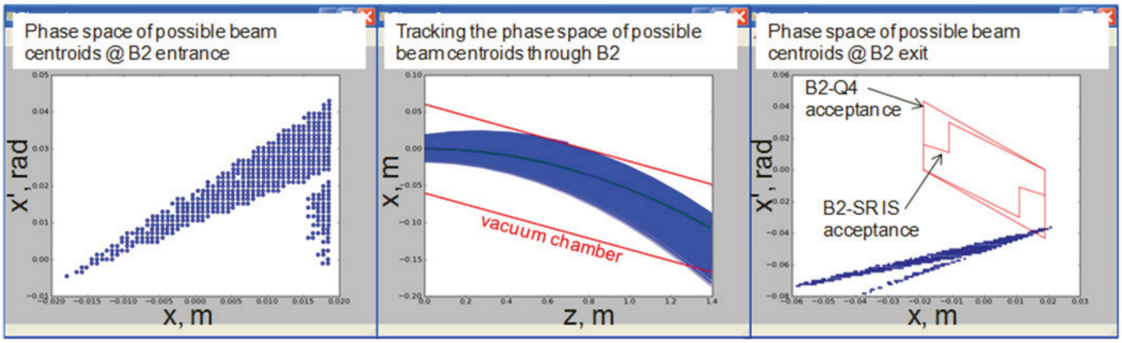

Figure 4: Studies of B1-B2 interlock. The phase space at the entrance to B2 was obtained by tracking all possible beam centroids through the BSR line with B1 interlocked at its nominal value with +-2% window. The green trace in the middle plot shows B2 reference trajectory.

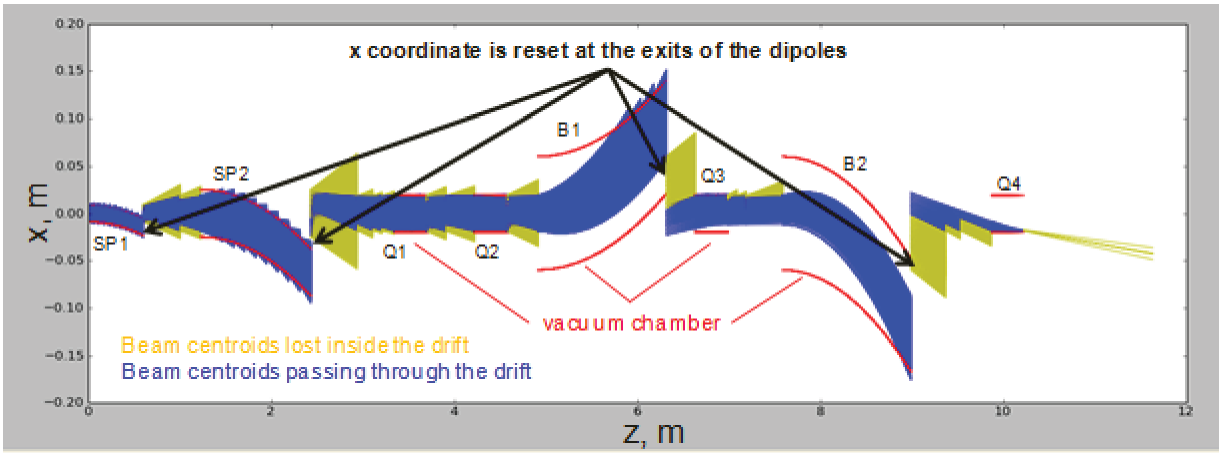

Figure 5: Tracking the phase space of 2 GeV beam centroids through the BSR. Dipoles B1 and B2 are interlocked at their nominal settings with +-2% window.

As Fig. 4 shows, although some of the beam centroids will reach Q4, none of them will be transported to SR injection septum. Varying the B2 settings within +-2% window doesn't change this conclusion. That means that interlocking B1 and B2 with +-2% window around their nominal 3 GeV values provides the required EI.

To double-check this result we perform additional tracking through the BSR. We track 2 GeV beam centroids with B1&B2 fixed within +-2% of their nominal values and rest of the magnets varied within their full range. As can be seen from Fig. 5, beam centroids do not propagate farther than Q4. A few centroids passing through Q4 are lost in Q4-Q5 drift.

We followed described procedures to study the case of EI that includes B2 only. It was found that even 0% window interlock on B2 does not filter out beam energies below 2 GeV.

Finally, we explored B1-B2 interlock with various widths of interlock windows. We found that the window width above 10% does not provide necessary EI. Therefore, we suggested using B1-B2 interlock with +-5% window. Such settings would be easily achievable from engineering point of view and would be comfortably far from the interlock window width that limits applicability of the EI.

The suggested energy interlock has been implemented and is currently used in commissioning of NSLS-II storage ring.

CONCLUSIONS

In this paper we presented the studies of energy interlock for NSLS-II storage ring commissioning. We applied dedicated tracking codes to studying various cases of possible interlocks. We found that interlocking BSR bends B1 and B2 at their nominal 3 GeV settings with +-5% window provides the required energy filter. This energy interlock has been applied and is successfully used for storage ring commissioning.

ACKNOWLEDGEMENTS

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