

EXPERIENCE WITH FIRST TURNS COMMISSIONING IN NSLS-II STORAGE RING

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Abstract

In this paper we describe our experience with commissioning of the first turns in the NSLS-II storage ring. We discuss the problems that we encountered and show how applying a dedicated first turns commissioning software allowed us to diagnose and resolve these problems.

INTRODUCTION

The first phase of the NSLS-II Storage Ring (SR) commissioning [1-3] took place in the spring of 2014. As a result of the first phase the routine injection efficiency of better than 90% was achieved. The beam was successfully accumulated up to 25 mA. One of the main challenges in establishing the beam in the SR was obtaining first few turns.

Below we describe our experience with obtaining first few turns and eventually a spiralling beam in the NSLS-II Storage Ring.

SR DESCRIPTION

The 3 GeV Storage Ring [4] consists of 15 short straight (low- β) and 15 long straight (high- β) sections. It contains 30 double bend achromats (DBA). The SR lattice is shown in Fig. 1.

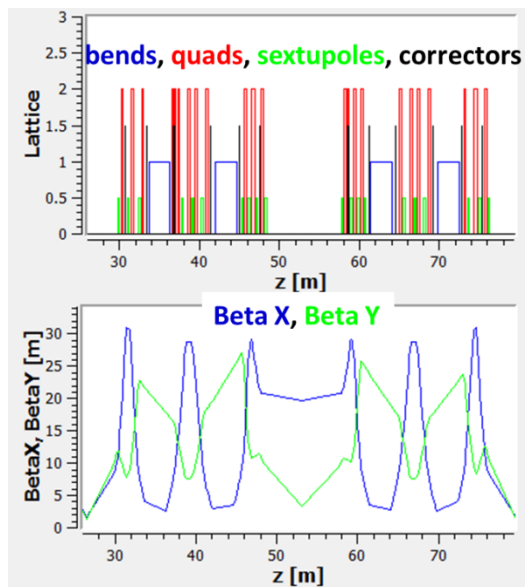


Figure 1: NSLS-II Storage Ring lattice.

Injection into the SR is performed with the aid of the DC and pulsed injection septa and four fast kickers forming a closed bump [5]. The injected beam exits the

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pulsed septum parallel to and with -24.5 mm displacement from the central axis of the injection straight section. In design injection scheme the stored beam is moved in the injection region towards the injected beam and returned back on axis at the exit of the fourth kicker. The injected beam has residual betatron oscillations of about 10 mm at the exit of injection section. Schematic of injection section (IS) is shown in Fig 2.

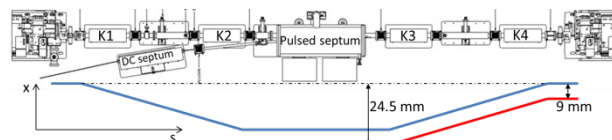


Figure 2: SR injection section and designed injection scheme (red colour represents injected beam, blue colour represents stored beam).

FIRST TURNS AND ON-AXIS INJECTION

The initial SR lattice was set to the design values. All SR sextupoles were set to zero current for the first turn commissioning. For the safety reasons the beam charge during initial commissioning was kept below 1 nC and injection rate was 0.3 Hz.

We decided to perform initial injection in the SR on axis, i.e. to minimize the betatron oscillations of injected beam. To achieve on-axis injection we applied horizontal -11 mm DC bump, which was created with the aid of regular beam trajectory correctors, on top of the AC bump in the injection straight. An example of such symmetric DC bump is shown in Fig. 3.

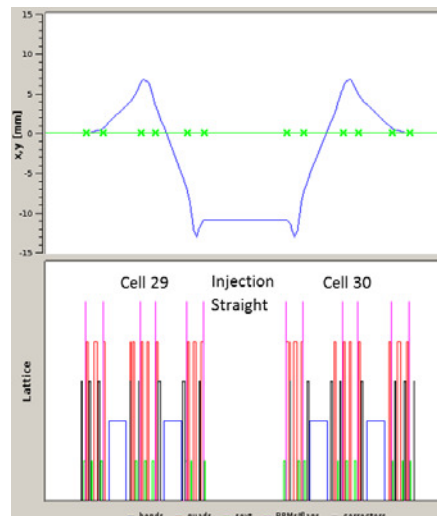


Figure 3: Horizontal DC bump in injection straight section.

After commissioning the Booster to SR transfer line the beam was successfully transferred through the SR AC septum without any noticeable problems. Nonetheless, although the design SR lattice along with nominal settings of kickers 3 and 4 and pre-calculated DC bump were loaded, the beam was observed only on the first few BPMs in the SR.

After kickers 3 & 4 were adjusted from their nominal 8.4 kV setting to 7.9 kV and 3.4 kV respectively the one complete turn was observed in the ring with significant beam loss and huge horizontal betatron oscillations.

As the next step, we used a dedicated first turns analysis software tool (FTA) [6] to bring the injected beam to the nominal central trajectory at the end of Cell 1. Then we went through the ring cell by cell utilizing FTA to correct horizontal beam trajectory to few millimetres. Fig. 4 shows an intermediate result of this process when horizontal trajectory was corrected down to Cell 4.

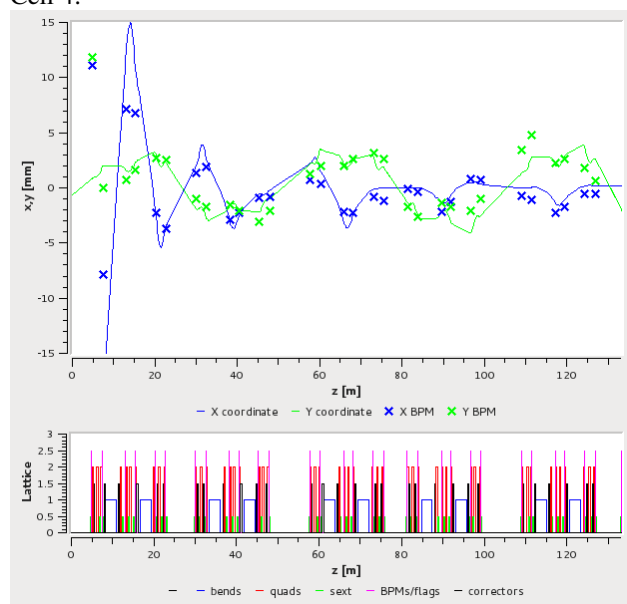


Figure 4: Snapshot of the FTA interactive plot showing live BPM readings and simulated trajectory of injected beam on the first turn down to Cell 4. The plot corresponds to first iteration of correcting first turn horizontal trajectory.

After two iterations of correcting both horizontal and vertical trajectories we managed to align the first turn trajectory in the SR to ± 2 mm horizontally and ± 1 mm vertically. While correcting vertical trajectory was trivial, horizontal trajectory could not be corrected to values better than a few mm because of shot to shot oscillations of the beam in X-plane. After trajectory corrections we obtained two turns in the ring.

Although first turn was well corrected we observed large betatron oscillations on the 2nd turn, even though we brought the injected trajectory to 0 angle/displacement in cells 30-01 and implemented the first half of design DC bump in cell 29. This indicated that the beam exits the injection straight section with a trajectory far from the designed one.

To reduce the betatron oscillations on the second turn we had to adjust the correctors in Cell 29 by a lot, thus, completely destroying the designed DC bump. Nonetheless, these new settings gave us a clearly visible 3rd turn in the ring.

All the aforementioned observations suggested that there was a problem with injection into SR ring. Therefore, we performed dedicated studies of SR injection.

We used FTA to measure beam coordinates at the exit of the IS and studied the effects of various settings of kickers 3 and 4 on the beam trajectory.

First we turned both kickers 3 and 4 off and we still could see the beam on first 4 BPMs in Cell 30. Although the readings were not very reliable, we found the beam displacement at IS exit to be ~ -20 mm, and $X' \sim 2.5$ mrad.

Next, with kicker 3 (and only kicker 3) on and at 4 kV we obtained three complete turns in the ring. The measurement of injected beam coordinates out of the IS showed $X = -22.8$ mm, $X' = 0$ mrad. This told us that kicker 3 had a negative kick, while by design it had to be positive (kicking the beam outside of the ring). We also checked that increasing kicker 3 voltage decreased the trajectory angle and decreasing the voltage increased the angle.

Finally, with kicker 3 on we turned on kicker 4; we observed that increasing kicker 4 consistently increased the beam trajectory angle, which indicated that kicker 4 had positive angle, again opposite of the design.

Thus, we concluded that the kickers 3 and 4 had wrong polarity. Indeed, changing polarity of injection kickers resolved our problems and allowed us to obtain a spiralling beam.

After the kickers' polarity was corrected, both kickers 3 and 4 were set to 7.8 kV. We measured that the injected beam had $X = -8$ mm, $X' = 1$ mrad coordinates at the IS exit, which was rather close to the expected values. Following the algorithm described above we corrected the first turn trajectory and closed the orbit on the first turn (by creating the proper DC bump). This dramatically decreased the betatron oscillation on the following turns, and allowed us to obtain (with some minor tuning of the DC bump) about 30 turns in the SR.

Finally, turning the sextupoles on and correcting both horizontal and vertical tunes gave us 10k+ turns in the SR.

OFF-AXIS INJECTION

As mentioned above, the design injection into SR is performed off axis. The prerequisites for obtaining off-axis injection are that the closed orbit is established in the ring and a single shot injected on axis with the aid of the DC bump is stored with RF (it is worth reminding that on-axis injection does not allow for accumulation of the beam).

If such conditions are met then obtaining off-axis injection is a matter of merely removing the DC bump.

The DC bump can be removed with the beam stored in the ring. To do so one can gradually scale the DC bump down while simultaneously correcting the closed orbit.

Following the outlined procedure we went through multiple iterations of removing the DC bump and correcting the lattice to no avail. The beam injected off-axis could not survive more than just a few turns in the ring.

At that point we performed first dynamic aperture studies with the fast injection kickers. Since the stored beam excited by kickers 1 and 2 only emulates the exact conditions of the beam injected off-axis we used obtained data to investigate the injection problem.

The thorough analysis of recorded turn-by-turn (TbT) BPM data led us to the conclusion that there was a physical obstruction in Cell 10, which hindered off-axis injection. Indeed, the TbT data taken over several dates and various lattices and tunes showed that when viewed vs. turn number, beam losses occur in sharp steps (Fig. 5). When these sharp steps occur, the beam loss consistently happens at the same location in the ring, between BPMs 4 and 5 in Cell 10 (Fig. 6).

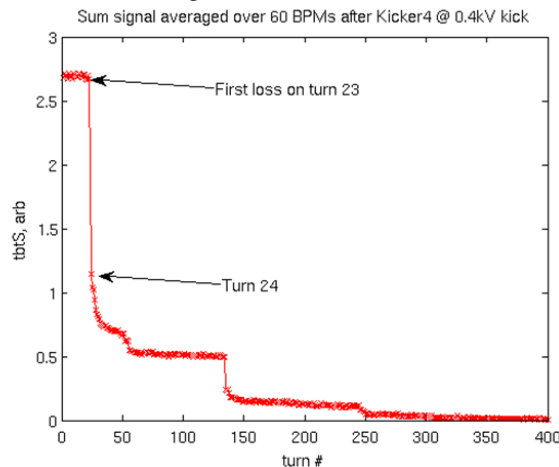


Figure 5: The beam loss as observed from the sum signals of SR BPMs.

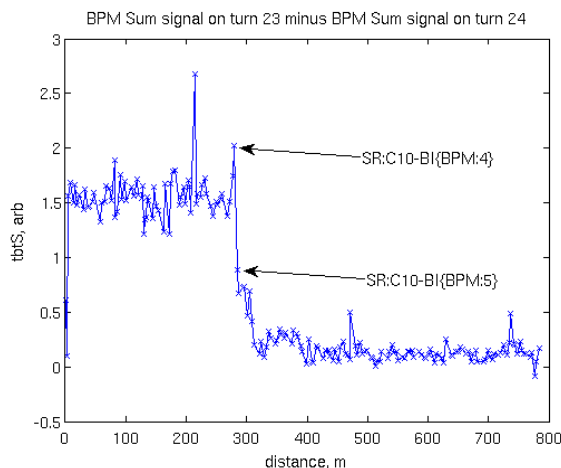


Figure 6: Difference of BPM sum signals between turn when the sharp loss occurs and the previous turn.

Since such behaviour suggested the presence of an abnormal physical aperture in Cell 10, this cell was investigated more with the aid of local bumps. These studies confirmed the presence of physical obstruction in Cell 10.

The vacuum chamber at the suspicious location was opened and an RF contact spring sticking from the top into the middle of the vacuum chamber was found.

After replacing and properly installing the RF spring in Cell 10, the off-axis injection was quickly obtained by following the procedure outlined above. Established off-axis injection immediately allowed for beam accumulation in the SR.

CONCLUSIONS

In this paper we discussed our experience with obtaining first turns in the NSLS-II Storage Ring.

We started with on-axis injection into a linear ring but initially could not obtain more than three turns in the SR. Investigating the source of the problem with the dedicated First Turns Analysis software tool we found that polarity of two injection kickers was reversed. After fixing this problem we quickly obtained a spiraling beam in the storage ring.

Obtaining first turns with design off-axis injection was not smooth either. Initially the beam injected off-axis could not survive more than just a few turns in the ring. By analysing the turn-by-turn BPM data for the stored beam excited with the fast kickers we came to the conclusion that there was a physical obstruction in Cell 10.

Indeed, when the vacuum chamber was opened in Cell 10 an RF contact spring sticking into the vacuum chamber was found. After fixing the spring the proper off-axis injection was quickly achieved.

ACKNOWLEDGEMENTS

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

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