STORAGE RING INJECTION KICKERS ALIGNMENT OPTIMIZATION IN NSLS-II*

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Abstract

The National Synchrotron Light Source II (NSLS-II) is a state of the art 3 GeV third generation light source at Brookhaven National Laboratory. SR is designed to work in top-off injection mode. The injection straight includes a septum and four fast kicker magnets with independent amplitude and timing control. Ideally, four fast kickers formed a local bump, which is transparent to stored beam during top off injection while shifting the injected beam closer to the SR beam close orbit with two downstream kickers. Due to mismatch of kicker amplitude, trigger timing delay or waveform, there is residual betatron oscillation. This disturbs SR beam stability during top off injection, which is specified as 10% of beam size and affects normal operation. This paper will present the injection kicker waveform measurement with beam, local and global alignment optimization to improve top off injection transition.

INTRODUCTION

The National Synchrotron Light Source II (NSLS-II) [1] is a 3 GeV, ultra-small emittance (H: 1 nm-rad and V: 8 pm-rad), high brightness third generation light source. The Storage Ring commissioning started in Mar. 2014 and started beamlines routine operation since Feb. 2015. Later top off injection was commissioned and implemented during normal operation in Oct. 2015 [2].

Injection kickers are designed as a local bump for stored beam. Due to mismatch of kicker's amplitude, trigger timing delay or waveform, there is residual betatron oscillation. This disturbs SR beam stability during top off injection. Even the injection transition decays quickly in a few hundred turns with bunch by bunch feedback system, but beam size blow out lasts longer, depending on radiation damping time and some beamlines are sensitive to this effect. In this paper, we described SR injection layout, kicker waveform measurement, kicker local and global alignment optimization to improve top off injection transition.

SR INJECTION OVERVIEW

The NSLS II storage ring injection system is located in one 9.3 m long straight section. As shown in Figure 1 cartoon, it consists of four fast kickers and a pulsed septum for beam injection. The four kicker magnets, producing a closed bump in x plane for stored beam, are placed symmetrically in the straight section. Their bending angles are the same but in different bend direction.

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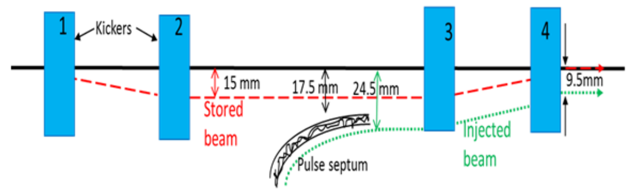

Figure 1: Cartoon of beam position during injection at SR injection straight section.

When the injected beam arrives, kickers K1 and K2 kick the stored beam towards the septum knife by 15 mm. The stored beam and the injected beam merge at the exit of the pulsed septum. Kickers K3 and K4 will kick both beam, so that the stored beam returns to close orbit, and the injected beam is off-axis oscillation. These kickers angle are 7.5 mrad with 5.2 µs kicker pulse length, two times long of storage ring revolution. The stored beam bump amplitude is 15 mm. The designed stored beam equilibrium orbit is 17.5 mm away from septum knife with 2.5 mm safe region away from septum knife. At the end of bump, injection beam is 9.5 mm away from stored beam close orbit [3]. There are 180 BPMs with turn by turn capability along the ring, which were used for the bump leakage study.

KICKER WAVEFORM MEASUREMENT

Each kicker has independent amplitude and timing control. The precision from kicker amplitude converted to the kick strength on beam is not sufficient to align kickers within specification [3] from the lab measurement and requires beam based alignment. The timing delay is separated into two control parts. One is for four kickers' common delay relative to the injection time, and the other is for each kicker precise delay to compensate the cable length or beam arrival time difference. The initial timing trigger for all kickers is aligned with the beam signal from BPMs raw data and monitored with oscilloscope.

The kicker waveform is half sine pulse shape with the pulse width about 2 turns of SR revolution. The kick strength on beam is the combination of kicker timing delay and amplitude, expressed as $A = A_0 * \sin(\omega(t + t_0))$, where A_0 is the kicker maximum amplitude, t_0 is the kicker individual timing trigger delay. SR different bucket beam gets different kick strength, depending on time t.

SR total RF bucket number is 1320. Beam filling pattern during normal operation is set as 80% fill with the rest bucket empty for ion instability, i.e. the first 1000 buckets fill. The injected bunch length vary from single bunch upto 150 bunches. To fill different bucket, SR kicker common timing delay varies related to bucket number and keep the fresh injected beam located at the same peak of kicker strength. So turn by turn beam

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position depends on the injection bucket and bunch filling pattern.

During initial commissioning, the first step to optimize kickers is to align injected beam on the peak of kicker waveform. This was done by exciting individual kicker at low voltage with a short bunch filled in the ring and scanned injection bucket number. After that, we optimized the kicker amplitude [4]. Four kickers amplitude were set to the same nominal value. The remaining betatron oscillation was about 1 mm. To minimize the residual leakage, four kickers' response matrix to 180 BPMs TBT data was used. The kicker voltage changes by 0.05 kV around its working point, so that the kicker calibration is in the working region and the BPMs reading is in linear region. We fixed kicker amplitude as the reference. After optimization, the leakage amplitude is lowered by half. The residual oscillation may come from kicker waveform mismatch and this cannot be corrected with kicker timing or waveform.

NSLS-II storage ring is equipped with transverse bunch-by-bunch (BxB) feedback system [5]. The system is capable to measure the turn to turn positions of each bunch. We used BxB ADC data to measure injection kicker waveforms. Horizontal betatron phase advances from injection kickers to the feedback pickup are close to n*180+90 deg and beam position reading at BBF is, $\sqrt{\beta_1\beta_2}sin(\varphi_{12})Ac$, proportional to kicker strength, which make the feedback digitizer ideally to measure the kicker waveforms. Here β is the beta function at kicker and BBF, φ_{12} is the phase advance between them and c is the coefficient to convert kicker amplitude to kick angle.

During study, storage ring was filled with all 1320 buckets except one to mark where the turn starts. Bunch to bunch current variation was small and the fill pattern was recorded to normalize the BxB sampled data if needed. Bunch to bunch data was synchronized with the injection kicker trigger. Since the kicker pulse width is about 2 turns, we decoupled different turn kick effect by setting horizontal fraction betatron tune at 0.25, i.e. one turn kick impacts on the same turn beam positon at BBF, but does not contribute to the next turn beam positon. The injected bucket is set at the middle of SR bucket 660, as shown in Figure 2. Horizontal axis is kicker waveform sampling index, vertical is the kick strength change with time. Four traces are kicker waveform measurement from digitizer and the rainbow cartoon represents two turns bunch train relative location during kicker excitation. With this special setting, the first one and half turn bunch by bunch beam position represents kicker waveform. After that, the beam position is the result of different turn kick combination.

To measure kicker waveform, they were excited individually at low voltage, 0.1 kV (VS nominal operation at 7.8 kV). The measurement result is shown in Figure 3. The left picture shows each bunch position reading in four turns from BBF output and the spikes indicates the empty buckets. We selected the first one and half turn data and fitted kicker waveform into half-sinwave function in black curve, as shown in the right plot. The fitting result shows four kickers' peak relative misalignment, pulse length and amplitude information, which agrees with the kick raw data in Figure 2. K4 is the longest pulse. Based on fitting result, we adjusted timing to align kicker peak value and scale the amplitude so that the injected buckets are aligned. It turned out the new setting excited bigger residual oscillation from waveform mismatch and beam cannot inject well.

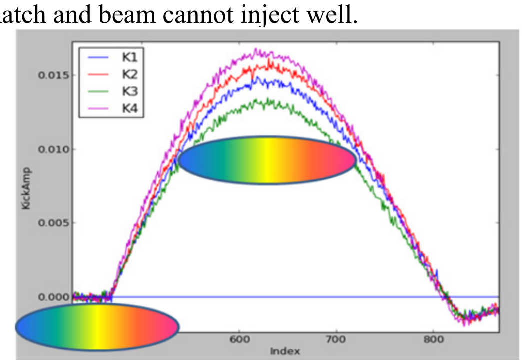

Figure 2: Bunch train distribution relative to kicker waveform during kicker excitation.

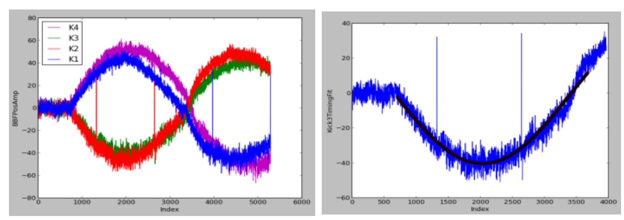

Figure 3: Bunch by bunch position measurement in four turns (left) and kicker waveform fitting (right).

Since the kicker waveform adjustment requires tunnel access and needs special arrangement, we decided to do kicker global optimization by minimizing injection residual oscillation, as described in the next section.

KICKERS GLOBAL OPTIMIZATION WITH RCDS METHOD

The method, robust conjugate direction search (RCDS) optimizer [6], is a general algorithm for multi-variable, noisy objective online optimization. It has been developed in SLAC for accelerator tuning and successfully applied for different purposes in SPEAR3, SLAC, ESRF [7], such as minimization of vertical emittance, injection efficiency improvements, lifetime optimization, etc. The main advantage of the method is its capability to find the optimum in a noisy environment, which makes it suitable for automated tuning. This perfectly fits the goal of injection transition optimization in NSLS-II.

The RCDS algorithm has two components: Powell's algorithm to update the conjugate direction set and the robust line optimizer to look for the minimum on each direction. The toolbox is developed in Matlab and Python environment. Since the code is written to be generally applicable. When applied the algorithm to a new problem, we only need to provide an objective function and launch the algorithm. In the algorithm, it includes the variable knobs, set limit range, object noise level, scan step, etc.

During beam study, we used the Matlab environment. The goal is to minimize beam residual oscillation during top off injection with one long bunch train, 80% bucket fill and small bunch to bunch charge variation. The parameters to be adjusted are the amplitude and timing delay for kicker 1, 2 and 3 while the kicker 4 parameters are fixed. So there are a total of 6 variable knobs. The residual oscillation amplitude is measured with 180 BPMs turn by turn position in x plane. The objective function is the RMS value of betatron oscillation from a few turns' data after kick excitation.

During the study, the initial kickers' setting is in operation value, with the same kicker amplitude. We did the optimization in three steps with different knobs combination. First, we varied 3 kickers' amplitude only and monitored the residual betatron oscillation from one fixed bucket excitation. This step showed very fast converges, within one hour, and minimized the injection transition from mm close to noise level, ~0.1 mm peak to peak, which is dominated by kickers' shot to shot variation. With the optimized kicker amplitude set, we varied 3 kickers' timing delay further and repeated the same optimization process. As predicted, the above two steps worked very well to minimize the injection transition in a fixed injection bucket, but other buckets still have large transition. In the last step, we varied both amplitude and timing with all the buckets excitation, from bucket 0, 100, to 1000, similar as top off injection and the objective function is the average value RMS value in each bucket. This step benefits from the first two steps' optimization by setting the knobs close to optimal value, but still took longer, about four hours to reach minimum, as shown in Figure 4, the BPM TBT residual oscillation along SR in many turns. The peak to peak oscillation improves obviously, from 1 mm with original set (top) to 0.1 mm after optimization (bottom) for a fixed bucket injection. Since the residual oscillation is injection bucket dependence, Figure 5 compares oscillation RMS value at different injection bucket with different kicker optimization result.

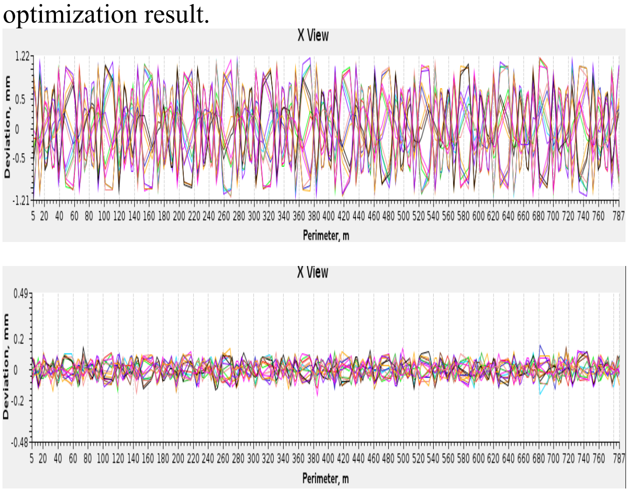

Figure 4: Top off injection transition from BPM TBT data before (top) and after (bottom) kicker optimization.

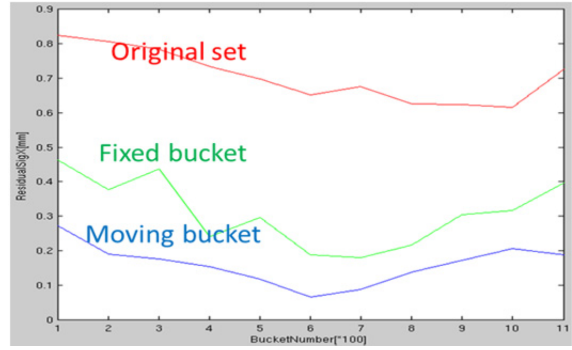

Figure 5: BPM TBT data RMS value dependence on injection bucket after local and global optimization.

CONCLUSION

The NSLS II storage ring is in routine top off operation. Injection kickers' mismatch caused injection transition was studied. We characterized the kicker waveform with bunch by bunch feedback system. We used RCDs method to optimize injection kicker timing and amplitude locally and globally and minimize top off injection transition effectively. Kicker waveform difference is the dominate impact of residual oscillation and will be done for offline adjustment.

ACKNOWLEDGEMENTS

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