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TRANSVERSE RESONANCE ISLANDS BUCKETS AT SPEAR3*

Jaehyun Kim†, J. Safranek, K. Tian
SLAC National Accelerator Laboratory, CA, USA

Abstract

We have explored a possible operation mode for timing experiments at SPEAR3 by populating a single bunch into the transverse resonance islands buckets (TRIBs), driven either by the multi-bunch feedback kicker over multiple turns or by one of the injection kickers within a single turn. In this paper, we present both experimental observations and numerical simulations for TRIBs studies at SPEAR3.

INTRODUCTION

Beam resonance in a storage ring is generally considered as a limiting factor for the beam performance. Therefore, operational betatron tunes are chosen to avoid harmful resonance lines such as those of integer tunes and half-integer tunes. When a potential-well is formed around a certain resonance, a bunch can be trapped inside the potential-well. This transverse resonance islands buckets (TRIBs) can be exploited to provide a bunch which has a different repetition rate and a spatial separation from the bunch circulating the ring on the nominal orbit. The TRIBs can be useful for some timing experiments in the beam line.

TRIBs have been studied and demonstrated at BESSY II [1] and MAX-IV [2]. Both studies focused on the 3rd order horizontal resonance by moving the horizontal tune, ν_x, close to 0.3333 (or 0.6666) and driving the beam to the TRIBs with the bunch-by-bunch (BxB) feedback kicker. Since the kick amplitude generated by the BxB kicker is small, a bunch will be diffused to the 3 islands evenly.

In this paper, we present experimental and numerical studies on TRIBs at SPEAR3. It was found that the beam can be driven to the TRIBs by using either the BxB feedback kicker or one of the injection kickers, K1. In either approach, instead of being populated to three islands, the beam was completely driven to one of the resonant islands.

SPEAR3 TRIBS MODE

SPEAR3 is a 3 GeV storage ring based on the double bend achromat (DBA) lattice with a circumference of 234.144 m. The 6-nm latice is an operational mode under development. Though it is not ready for user operations, the 6-nm lattice provides adequate lifetime and injection efficiency for accelerator physics experiments. In addition, the designed ν_x is 15.32, convenient for the TRIBs studies. As a result, the 6-nm lattice was chosen for this work. The nominal chromaticity of the 6-nm lattice is +2 for both the horizontal and the vertical planes. During our TRIBs study, the horizontal chromaticity was reduced to 0 using a chromaticity response

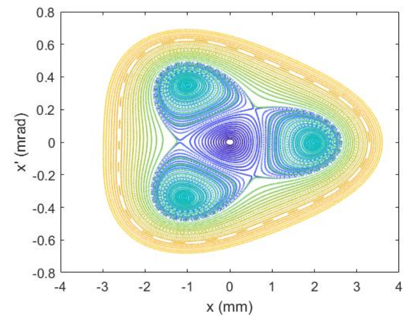

Figure 1: Contours on the x-x' phase space at s = 0 position.

matrix to avoid tune shifts caused by momentum deviation when driving the beam horizontally. We were able to drive the TRIBs mode either with the BxB feedback kicker or the injection kicker, K1, however, with the BxB feedback kicker, ν_x was increased to 0.3297 from the design value of 0.32 due to the relatively weak strength of the kicker [3].

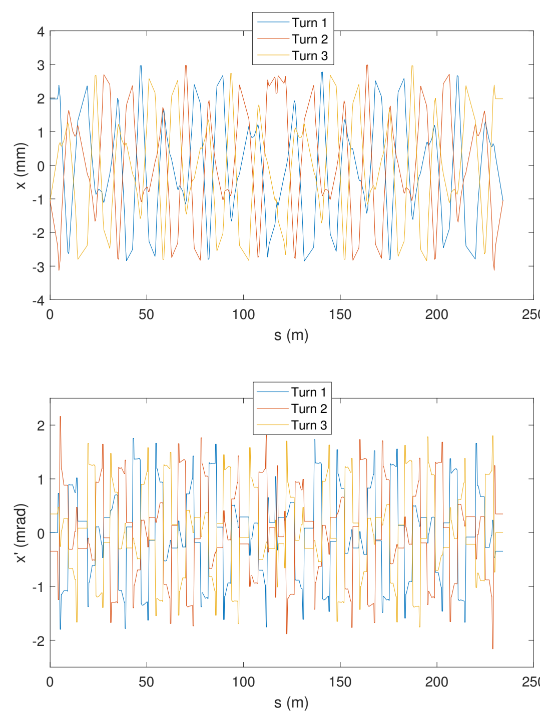

Figure 2: Closed orbit of SPEAR3 TRIBs optics.

Using ELEGANT [4], single particles with varied initial offsets were tracked in a lattice obtained from optics fitting with LOCO [5]. The distribution of resonance islands is visualized in Fig. 1 as three potential wells around ν_x = 0.3333. Once the electron beam is trapped in one of these islands, the new orbit (x, x'), passing through the centers of the 3 islands as shown in Fig. 2, is closed every 3 turns. The

* Work supported by U.S. Department of Energy under Contract No. DEAC02-76SF00515
† jaehyun@slac.stanford.edu

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maximum of x is about 3 mm. It is possible to adjust the beam orbit to achieve large offset in x or x' in the straight sections by tuning the lattice parameters, however, this was not tried yet in our study.

TRIBS WITH THE BXB FEEDBACK KICKER

During the experiment, a single bunch of 18 mA was filled initially. The beam was populated to the TRIBs orbit at various beam current, but normally we refilled the bunch back to 18 mA if it was decayed below 6 mA. The BxB kicker was driven for 1*ms* with a frequency sweep from 422 kHz to 426 kHz, with 426 kHz corresponding to the 1/3 horizontal tune of SPEAR3.

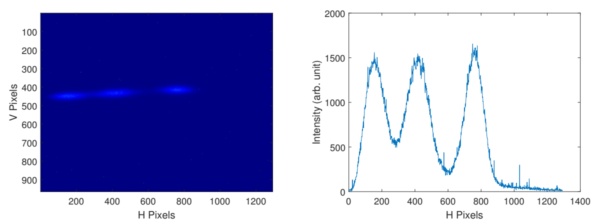

Figure 3: Pinhole camera image (left plot) and projection on the horizontal axis (right plot). A bunch is excited to TRIBs with the BxB kicker.

It was found that the beam stayed in the TRIBs islands for more than tens of minutes without damped motion. The three islands can be spotted in the image taken from a x-ray pinhole camera in Fig. 3. The projection on the horizontal axis reveals 3 peaks with about the same integrated area, which is due to the long exposure time of the camera. We

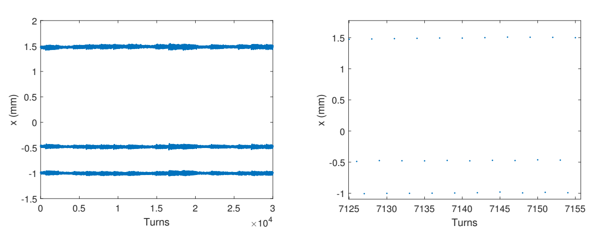

Figure 4: Turn-by-turn BPM data for horizontal plane. A bunch is excited to TRIB with the BxB kicker.

also took the beam orbit data using a SPEAR3 turn-by-turn (TbT) BPM [6]. In Fig. 4, the TbT BPM data clearly shows 3 separated trajectories in x, through which the beam cycles. It appears, from the TbT BPM data, all electrons in the bunch were driven to one of the three islands initially. If the three islands were populated equally, the TbT BPM data would show x ~ 0 mm as averaged position of 3 islands are close to 0. This characteristic can be used to provide a beam with reduced repetition rates, which could be desirable for some beam line experiments.

In Fig. 5, we show the simulation results at the source point of the pin-hole camera and the location of the SPEAR3 TbT BPM, which shows that at both locations, two islands are close to each other in x plane. This is consistent with the measurement results from the pin-hole camera and the TbT BPM. We further quantify the separation of the islands in Table 1, where the calibration factor of 2 μm/pixel was used for the pin-hole camera. The agreement between the measured data and the simulations confirms that only one island was populated.

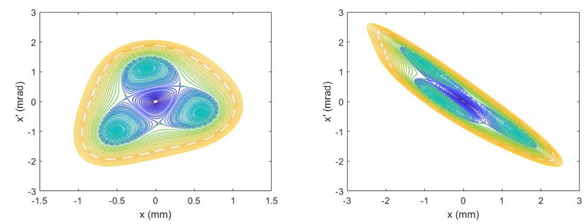

Figure 5: Contours on the x-x' phase space at the pinhole camera source position (left plot) and at the TbT BPM position (right plot). Lattice : TRIBs mode.

Table 1: Islands separation for measurement and simulation. R-M is the separation between the right island and the middle island. R-L is the separation between the right island and the left island.

Position	R-M (mm)	R-L (mm)
Pinhole camera (meas.)	0.68	1.22
Pinhole camera (simul.)	0.71	1.09
TbT BPM (meas.)	2.00	2.59
TbT BPM (simul.)	2.06	2.47

The $x - x'$ phase space at the BxB kicker position is plotted in Fig. 6. The center of two islands has relatively large offset in x ($\pm$2.5 mm), while the center of the other island has nearly 0 offset in x. It is possible that the beam is easier to be driven to the latter island due to the small offset in x.To verify this theory, we are planning to take single turn images of the TRIBs excitation with a fast gated camera [7]. The measurement will also directly confirm if only one island was populated.

TRIBS WITH K1 KICKER

SPEAR3 has 3 injection kickers (K1, K2, K3) for closed orbit bump during the off-axis injection. The K1 kicker can provide much stronger kick than the BxB feedback kicker, so we could keep ν_x at the design value of 0.32. During our experiment, the beam was kicked to the TRIBs island with a single kick from the K1 kicker with the strength of about 0.6 mrad. We were able to capture part of the transient motion of the beam from the nominal orbit to the island orbit with the TbT BPM as shown in the lower left plot in Fig. 7. After ~25000 turns, the beam is stable in the island

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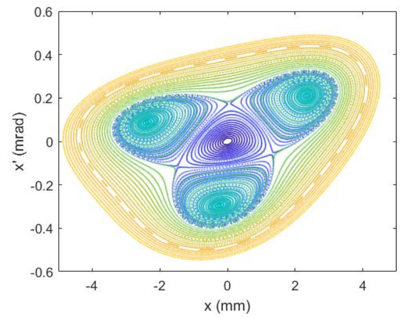

Figure 6: Contours on the x-x' phase space at the BxB kicker position. Lattice : TRIBs mode.

orbit (the lower right plot in Fig. 7). It also shows that the island separation is larger than that driven by the BxB kicker. This is because, in this case, the bunch was excited from $\nu_x = 0.32$, further away from the one-third resonance.

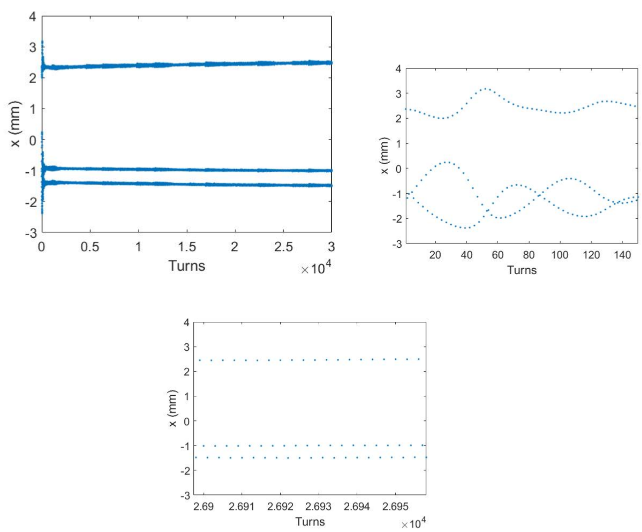

Figure 7: Turn-by-turn BPM data for horizontal plane. A bunch is excited to TRIBs with K1 kicker.

The distributions of the TRIBs islands at the location of the TbT BPM and the K1 kicker are shown in Fig. 8 for the 6-nm lattice. One can note that at the K1 kicker, one of the three islands has small offset in x and larger offset in x', which could be the preferred island to attract the particles when the K1 kicker is pulsed. The calculated results for the island separation distance at the TbT BPM also shows good agreement with the the measurement results in Fig. 7. All these observations indciate that the beam, when driving with the K1 kicker, was populated to one island. We expect that further investigation on the transient dynamics shown in Fig. 7 can reveal more physics such as the strength of the potential-well and the detailed process of bunch trapping.

Tracking studies were set up to simulate the TRIBs experiments by creating a single turn kick at the K1 location with 2000 particles in the equilibrium distribution. The strength of K1 was scanned to search for the best matching results

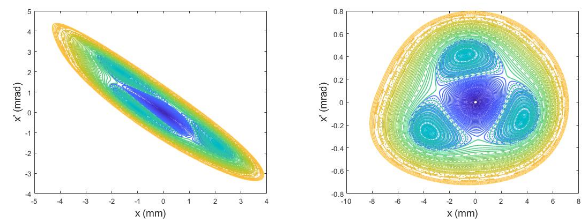

Figure 8: Contours on the x-x' phase space at the TbT BPM position (left plot) and at K1 kicker position (right plot). Lattice : 6-nm mode.

of the island separation distance to the measurements. It was found that, as shown in Fig. 9, the results with the kick strength of 0.44 mrad agreed well with the measured data in Fig. 7. When the kick strength was below (0.30 mrad) or above (0.50 mrad) this value, smaller separation distances were observed, which indicated that some particles were not trapped inside the islands and moved back to the core. The tracking simulation describes transient dynamics toward TRIBs well despite no collective effects were included in the simulation.

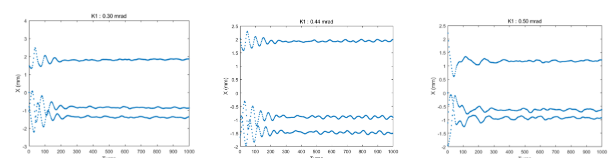

Figure 9: Centroid motion for varied K1 strength: 0.30 mrad (left plot), 0.44 mrad (middle plot), and 0.50 mrad (right plot). Results of particle tracking simulation with 2000 particles.

CONCLUSION

We have experimentally demonstrated TRIBs in the horizontal plane at SPEAR3 by driving the beam either by a BxB feedback kicker or an injection kicker, in the 6 nm lattice. The measured results at the TbT BPM and the pin-hole camera agree well with simulation results. Different from other studies, the single bunch was driven to one island instead of populating to all islands evenly. Further studies are planned to understand the transient dynamics of the bunch trapping and to explore the possibilities of driving TRIBs in the vertical plane.

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