ISBN: 978-3-95450-214-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2021-TUPAB217

EFFECT OF UNDULATORS ON TRANSVERSE RESONANT ISLAND ORBITS

E. Rial†, J. Bahrdt, P. Goslawski, A. Meseck[1], M. Ries, M. Scheer
Helmholtz-Zentrum Berlin, BESSY, Berlin, Germany
[1]also at Institute for Nuclear Physics, Johannes Gutenberg University, Mainz, Germany

Abstract

For one week in October 2020, BESSY II offered a Two Orbit mode to users for the first time. In this Two Orbit mode, the existence of transverse resonant island buckets is exploited to store a second beam in the storage ring as an 'island orbit', away from the primary beam axis. This mode was offered with free range of motion of the 12 out of vacuum undulators installed in the BESSY II ring. Diagnostics of the island orbit were limited to a single camera, monitoring bending magnet radiation from a single dipole. A significant motion of the island orbit was observed on this diagnostic and correlated with undulator gap motion. This observation is reported, and simulations presented to demonstrate how this motion could arise. Correction schemes are suggested.

BACKGROUND

In the last few years, the team at Helmholtz-Zentrum Berlin (HZB) have been developing a two-orbit mode based on the phenomenon of Transverse Resonant Island Buckets (TRIBs) [1, 2]. The island orbit closes after three turns, in opposition to the core orbit that closes following a single turn. This technique has now matured and is now able to be offered as a scheduled user week at BESSY II.

For this user week, a single 3 mA bunch was stored in the second 'island' orbit, and 295 mA was offered in the regular orbit to maintain a standard offering to users uninterested in exploiting the single bunch. One possible application for TRIBs operation is a bunch separation scheme offering multi-bunch and single-bunch operation simultaneously. Figure 1 shows a view of the beam, as seen on a pinhole camera dipole downstream of the D5 straight.

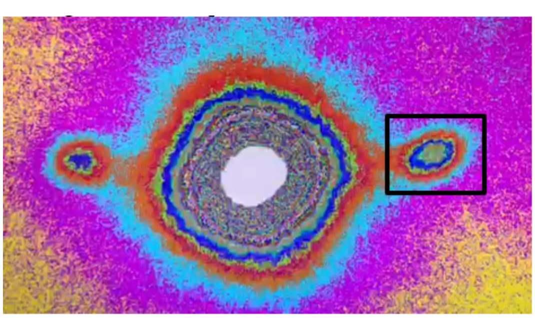

Figure 1: Two-orbit mode. The intensity ratio between the core orbit and the island orbit is ~ 0.0034. The colour scale was chosen such that a good fit could be obtained over the sampled region (black rectangle), which was the only available beam diagnostic element for the island orbit.

† ed.rial@helmholtz-berlin.de

In preparation for the week-long operation, several undulators were checked to confirm that tune feedforward, and correction coil tables were suitable, and that they would not disturb the core orbit. No significant disturbances were seen; however, no assessment was made of the island orbit. The main reason for a lack of assessment was a lack of diagnostic elements. Indeed, the only available diagnostic was the pinhole camera of Fig. 1.

As the island orbit contained only ~ 1% of the peak current, the core orbit dominated the measurements on the diagnostics used for beam position feedback, and so these systems were relied upon to maintain a stable core beam.

USER WEEK OBSERVATIONS

The user week was very successful. Availability exceeded 99% and over the course of the week of top-up operation, the average injection efficiency of the ~ 6000 shots was above 95%.

As is usual in a user week the users were given freedom to move their undulator sources as desired. The core beam was well corrected with the usual feed-forward and feedback systems. There was, however, a noticeable effect on the island beam as can be seen in Fig. 2.

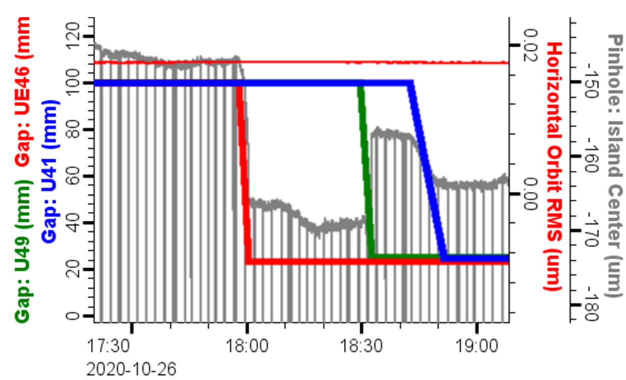

Figure 2: Island wander during TRIBs user beam. The core orbit is well controlled, but the island orbit drifts correlate with undulator motion. The 30 μm scale of motion is significant compared to the beam spot size, $\sigma_{x,y}$, of ~ 75 μm.

DETAILED STUDIES

In order to more precisely study this effect, the island orbit was studied in isolation, with a depopulated core orbit. A single turn of the island orbit was populated with a 2/3 length bunch train, and the remaining two turns left empty. This enabled each turn to be observed individually by fast bunch-by-bunch beam position monitors (BPMs) as the train travelled along each turn.

ISBN: 978-3-95450-214-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2021-TUPAB217

There were three fast BPM systems available. Two striplines [3], pxi1zs7g and pxi4zs12g, located in Straights D5 and D7, and a standard BPM connected to a Libera processor [4]. The pinhole system downstream of Straight D5 was also used to monitor the position of the same turn as the original observation.

Three devices were selected for study: a 49 mm period planar hybrid undulator (U49-1), and two APPLE II undulators of 46 mm and 52 mm period length (UE46 and UE52). The undulators were scanned from 100 mm to their minimum gap, and the APPLE II undulators were scanned along the length of their shift motion at minimum gap.

RESULTS AND ANALYSIS

Pinhole Camera Measurements

The results from the pinhole camera confirmed that there is a significant effect on the island beam position at gaps less than 40 mm. Although from Fig. 3 it may appear at first glance that the direction of the disturbance is not consistent from undulator to undulator, this is perhaps less surprising when one considers how variable the optics functions of the three turns are.

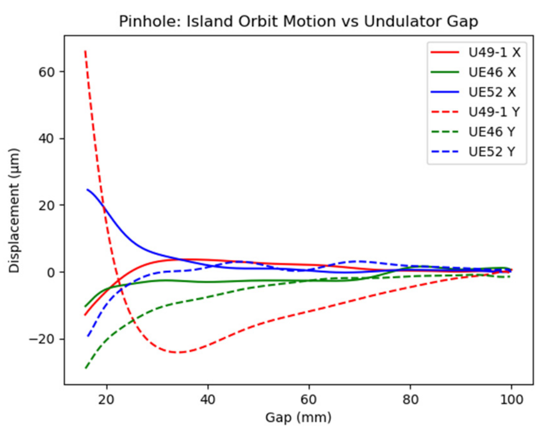

Figure 3: Motion on pinhole camera versus undulator gap.

Figure 4 displays the impact of the elliptical undulators on the island orbit at the pinhole camera against shift. Again, this does not immediately point to any consistency in how the undulators impact the beam. A full orbit calculation accounting for the optics functions (Fig. 5) at each device needs to be completed to be able to draw any firm conclusions.

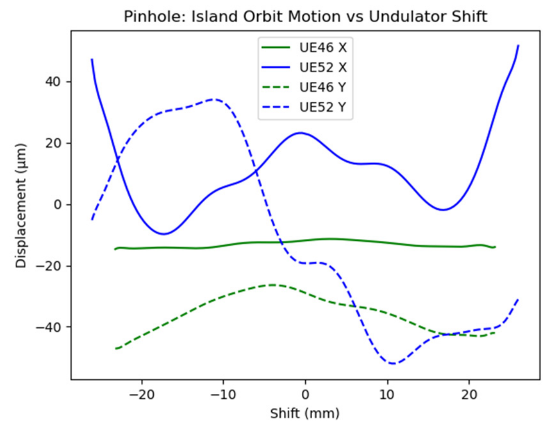

Figure 4: Motion on pinhole camera versus undulator shift.

The pinhole camera results show clear and compelling evidence that the undulators are causing beam movement of the island orbits, but do not show the complete picture as they only illustrate what is happening to one of the three island orbits.

Bunch by Bunch Stripline Measurements

The two stripline detectors allow for all three turns of the island orbit to be tracked, which allows for analysis and comparison of all three turns of the island orbit. For considerations of space, only the results of the UE52 device are discussed.

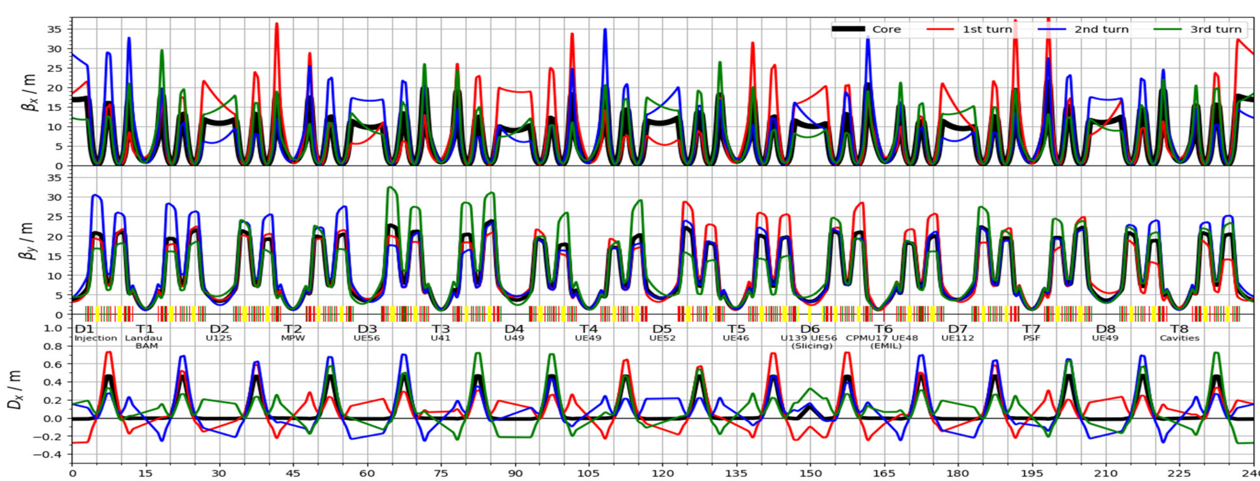

Figure 5: Optics functions of the TRIBs core and island orbits.

12th Int. Particle Acc. Conf. IPAC2021, Campinas, SP, Brazil JACoW Publishing
ISBN: 978-3-95450-214-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2021-TUPAB217

The horizontal deviation with gap shown in Fig. 6 became particularly pronounced as the undulator gap was driven below 40 mm. The direction of the deflection of turns one and three are opposed at each stripline for the effects due to both gap and shift, seen in Figs. 6 and 7. The direction of turn two appears to be similar in each position.

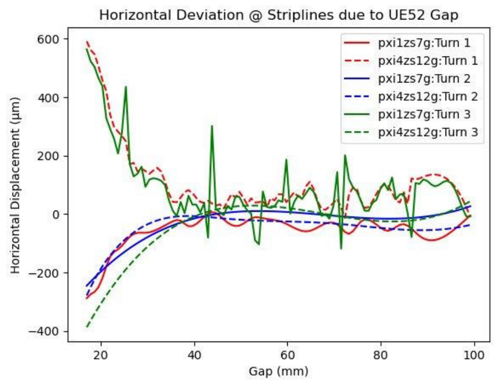

Figure 6: Orbit variation versus UE52 gap.

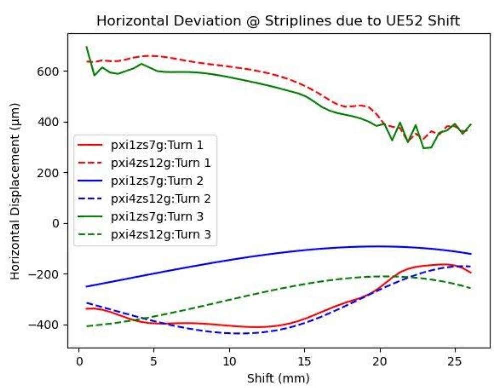

Figure 7: Orbit variation versus UE52 shift.

Comparison with Calculated Impact

The nominal trajectories of the turns of the TRIBs island orbit, shown in Fig. 8, were tracked through a detailed model of the UE52 device using WAVE [5], to assess how strong an effect the undulator has on each turn.

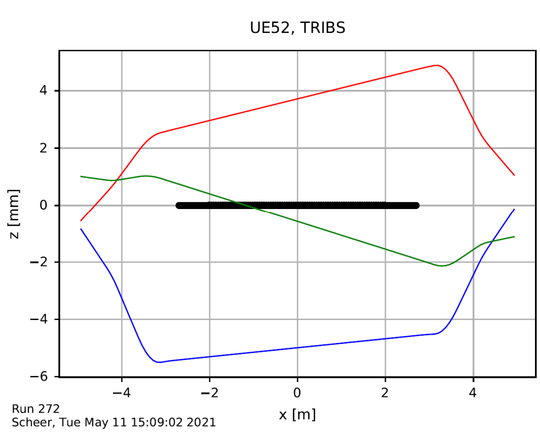

Figure 8: Trajectory of core (black) and island turn (red, green, blue) trajectories through straight D5.

It can be seen that the three orbit trajectories through straight D5 vary quite dramatically. Two of the turns are separated by nearly 10 mm, and the third turn follows a trajectory much closer to the nominal core orbit. This translates into very different trajectory kicks through the UE52 undulator for each turn as seen in Fig. 9.

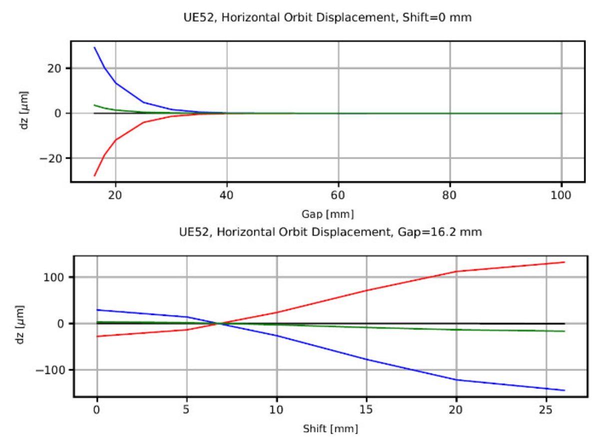

Figure 9: Single pass orbit displacement of island turns through UE52 vs. gap and shift, compared to the core orbit.

It is noticeable that the calculated kicks of two of the trajectories are large, and of opposing sign, similar to the results seen in Fig. 6. The model is also in agreement with when the effect of the undulator should be noticeable, i.e. at gaps below 40 mm.

A final indication of agreement is that when a shift is applied, the measured kick disturbance reduces, even if it does not change sign as the calculation suggests it should. A complete orbit calculation may offer more insight for this situation.

OUTLOOK AND FURTHER WORK

In all of this analysis, it should not be forgotten that undulators are tuned to function optimally for on-axis electron beams. Passive correction schemes such as magic fingers correct for errors in magnet manufacture and keep variation in field integral across the device down to a few Tμm, and active correction schemes such as dipole coils at the end of the device correct gap dependent field integral shifts. However, it is unlikely these existing correction schemes will be enough to correct four orbits simultaneously – the core orbit, plus three island turns.

It is clear that if TRIBs is to be fully exploited by users at BESSY II, the stability of the island orbit must be decoupled from undulator motion to allow beamlines the operational independence they require.

It is to be investigated as to whether a global correction scheme with quadrupoles or sextupoles will be sufficient, or whether local multipole correction coils will eventually be needed.

ACKNOWLEDGEMENTS

The authors would like to thank G. Rehm and F. Falkenstern for setting up the bunch-by-bunch BPM systems for these measurements.

ISBN: 978-3-95450-214-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2021-TUPAB217

REFERENCES

[1] M. Ries *et al.*, "Transverse Resonance Island Buckets at the MLS and BESSY II", in *Proc. 6th Int. Particle Accelerator Conf. (IPAC'15)*, Richmond, VA, USA, May 2015, pp. 138-140. doi:10.18429/JACoW-IPAC2015-MOPWA021

[2] P. Goslawski *et al.*, "Two Orbit Operation at Bessy II - During a User Test Week", in *Proc. 10th Int. Particle Accelerator Conf. (IPAC'19)*, Melbourne, Australia, May 2019, pp. 3419-3422. doi:10.18429/JACoW-IPAC2019-THYYPLM2

[3] F. Falkenstern, F. Hoffmann, J. Kuszynski, and M. Ries, "Accurate Bunch Resolved BPM System", in *Proc. 5th Int. Beam Instrumentation Conf. (IBIC'16),* Barcelona, Spain, Sep. 2016, paper TUPG03, pp. 312-315. doi:10.18429/JACoW-IBIC2016-TUPG03

[4] M. G. Abbott, G. Rehm, and I. Uzun, "The Diamond Light Source Control System Interface to the Libera Beam Position Monitors", in *Proc. 12th Int. Conf. on Accelerator and Large Experimental Physics Control Systems (ICALEPCS'09)*, Kobe, Japan, Oct. 2009, paper THP011, pp. 694-696.

[5] M. Scheer, "WAVE - A Computer Code for the Tracking of Electrons through Magnetic Fields and the Calculation of Spontaneous Synchrotron Radiation", in *Proc. 11th Int. Computational Accelerator Physics Conf. (ICAP'12)*, Rostock-Warnemunde, Germany, Aug. 2012, paper TUACC2, pp. 86-88.