ISBN: 978-3-95450-168-7 doi:10.18429/JACoW-IPAC2015-MOPWA021

TRANSVERSE RESONANCE ISLAND BUCKETS AT THE MLS AND BESSY II

M. Ries *, J. Feikes, T. Goetsch, P. Goslawski, J. Li, M. Ruprecht, A. Schälicke, G. Wüstefeld †
HZB, Berlin, Germany

Abstract

By operating the Metrology Light Source (MLS) near horizontal resonances (ΔQ_x = 1/2, 1/3 or 1/4), two, three or four resonance island buckets may be populated for beam storage. This paper presents experimental results and operational experience such as tuning the machine for high current, controlling inter-bucket diffusion rates, improving overall lifetime and extraction of radiation pulses with sub-revolution repetition rate. First approaches to transfer this mode of operation to the BESSY II storage ring will also be presented.

INTRODUCTION

The MLS is an electron storage ring operated as a dedicated light source for metrology applications of the Physikalisch-Technische Bundesanstalt (PTB). By design, it is equipped with additional families of sextupole and octupole magnets to manipulate nonlinear beam dynamics [1,2]. Therefore, the MLS is ideally suited to investigate nonlinear beam dynamics in the transverse plane.

Transverse resonance island buckets form when a machine is operated in the vicinity of a resonance and suitable amplitude dependent tune shift is present. The existence of these island buckets is well known and described for long time, e.g. [3]. An application is multi-turn extraction at CERN [4]. However, island buckets are not yet exploited for user operation at electron storage rings.

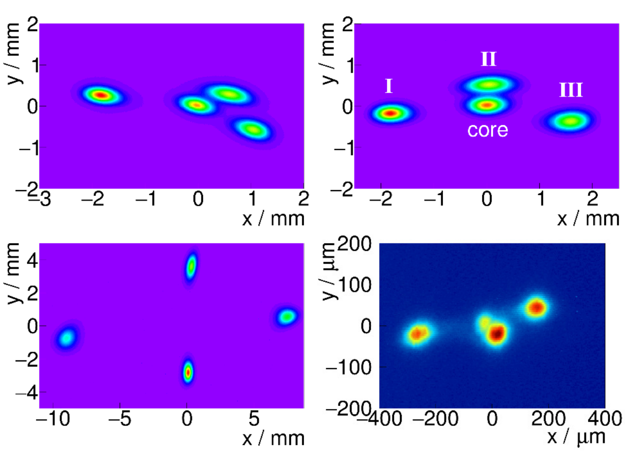

Figure 1: Source point imaging measurements from island bucket operation near horizontal resonances ΔQ_x = 1/3 (top) and 1/4 (bottom left) at the MLS and BESSY II (bottom right).

* markus.ries@helmholtz-berlin.de
† gwuestefeld@gmx.de

Figure 1 exemplarily shows transverse electron distributions measured using a source point imaging system. The MLS was successively operated near horizontal resonances $\Delta Q_x = f_x/f_{\text{rev}} = 1/3$ (top) and 1/4 (bottom left). Skew quadrupole magnets were used to introduce vertical separation for the purpose of visualization. The upper measurements were taken simultaneously at two different locations along the circumference. The position of the islands can be manipulated by changing quadrupole and sextupole currents. Islands stored near the ΔQ_x = 1/4 resonance are shown bottom left, with large off-axis fixed points. The core beam was not populated.

Studies for island bucket operation are also performed at the BESSY II storage ring, an example measurement is shown in the bottom right part. Resonance island buckets may provide an elegant way of beam separation – see next section – for the BESSY VSR project [5].

MULTIPLE BEAMS & SEPARATION

Two intrinsic characteristics of island buckets seem to be of special interest for application at light sources. First, island buckets offer the possibility to store two distinct user beams simultaneously, e.g. homogeneous fill and pseudo single bunch. Second, island bucket and core beams are separated in space and/or in angle in the plane corresponding to the resonance.

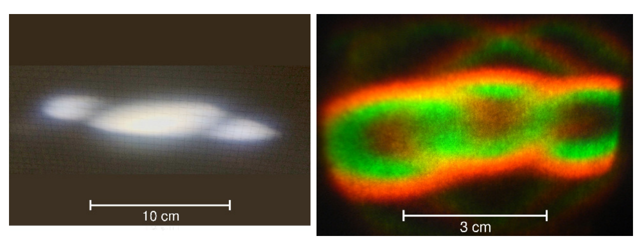

Figure 2: Photon beam separation in divergent parts of user beamlines shown for bending magnet radiation (left) and undulator radiation (right).

The separation in electron phase space translates to the generated photon beams. Figure 2 shows photon beams generated by island buckets in a bending magnet (left) and an undulator straight (right) in divergent parts of the user beamlines. The former image was taken with simultaneously populated island bucket and core beam. In contrast, the latter image was measured with exclusively populated island buckets. At the position of the undulator two islands are characterized by fixed points at ($x_{\text{FP}} \approx 0, \pm x'_{\text{FP}}$), whereas the third island is at ($x_{\text{FP}}, x'_{\text{FP}} \approx 0$). The achieved photon beam separation is in the order of cm, which is an accessible range

ISBN: 978-3-95450-168-7 doi:10.18429/JACoW-IPAC2015-MOPWA021

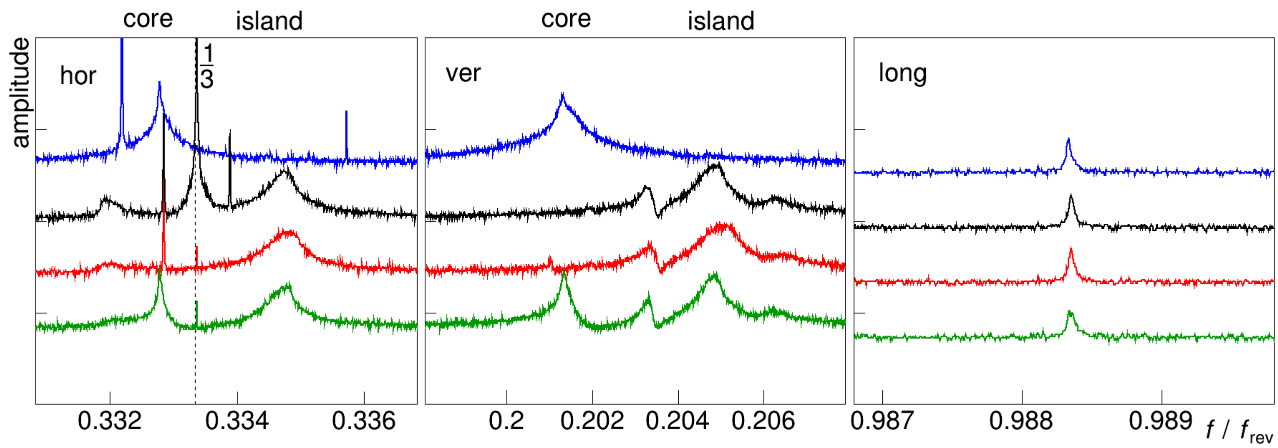

Figure 3: Tune characteristics of island bucket operation near $\Delta Q_x = 1/3$ were measured using a stripline detector. Different color codes correspond to exclusively populated core beam (blue), exclusively and homogeneously populated island buckets (red), an intermediate state with both buckets populated (green) as well as exclusive population of "a single island" (black).

for typically used apertures. Easier means of separating the photon beams for users is one of the main reasons for this paper to focus on island bucket operation near $\Delta Q_x = 1/3$.

OPERATIONAL ASPECTS

Key diagnostics for establishing island bucket operation at the MLS were source point imaging, tune measurement as well as an electron loss monitor. The target resonance was approached with about $\delta Q_x \approx 10^{-3}$. Two of three sextupole families were used to keep transverse chromaticities fixed at $\xi_{x,y} \approx 0$. The third sextupole family, a harmonic one, was used to adjust amplitude dependent tune shift. While preserving reasonable beam lifetime, island buckets were empirically cultivated through manipulation of horizontal tune and sextupole current. The source point imaging system turned out to be the most sensitive measurement tool for the early emergence of islands.

Figure 3 shows measured tune characteristics in all three planes for a fixed island optics with different bucket populations. The measurement was conducted in single bunch mode. An exclusively populated core beam is shown (blue), where the sharp spike at $\Delta Q = 0.3322$ corresponds to a weak sinusoidal excitation used to clear the island population. Exclusively populated islands are shown (red) – bucket clearing was applied at $\Delta Q = 0.3328$. It should be noted that the electrons equally distribute to all islands, which is indicated by the only faintly visible resonance line at $\Delta Q = 1/3$. A population with roughly half the current in island and core is shown (green). In this case no clearing is needed for properly adjusted bucket acceptances. The black graph corresponds again to exclusively populated islands, however, all particles were trapped in a single island – see next section.

Optimal clearing frequencies were obtained experimentally and are in agreement with the corresponding bucket tune or its mirror-mode. It should be noted, that particle redistribution between bucket types only works for phase space configurations with an embracing bucket around island and core.

The vertical tune is also different for island and core beam as the paths through nonlinear elements are different. In contrast, the longitudinal tune stays unchanged.

By now island buckets operation at the MLS near $\Delta Q_x = 1/3$ is reproducible and automated. The full current of about 180 mA may be stored equally distributed in the islands with a lifetime comparable to standard user operation. Longitudinal bunch by bunch feedback is required and operational [6]. Long term stability with respect to tune and source point position is well on the scale of hours. The beam size of individual islands is slightly increased by up to 20 % with respect to the core beam.

By the time of writing this article, it was possible to store up to 200 mA in the BESSY II storage ring. Island bucket operation with typical insertion devices seems to have no impact on position and shape of the islands. From the first experiments beam stability looks promising.

SUB-REVOLUTION REPETITION RATES

A very interesting characteristic of transverse resonance islands is given by the fact that the orbit of the islands closes after three turns. This is a distinct contrast to similar buckets in the longitudinal plane – α-buckets [2]. A single particle trapped in an island in the first turn (e.g. Fig. 1 (I)) will be observed in another island in the second turn (e.g. Fig. 1 (II)) and so forth. While performing betatron oscillations around the fixed points it will seemingly jump between islands in a matter dependent on the driving resonance.

Selective island population may be exploited to generate radiation pulses with sub-revolution repetition rates. This feature could contribute to techniques like time-of-flight spectroscopy at smaller rings. Injection directly into the islands is not possible at the MLS due to the lack of full energy injection. In addition, halo particles tend to generate drift rates between bucket types. Therefore, the proposed

ISBN: 978-3-95450-168-7 doi:10.18429/JACoW-IPAC2015-MOPWA021

scheme relies on resonant bucket cleaning as discussed in the former section.

To drive all particles into the very same island the nonlinearity of the kicker used for horizontal bunch-by-bunch feedback was adopted. The basic idea is to simultaneously apply clearing for core and island buckets. However, clearing for the island bucket should not be of equal strength for all islands. Therefore, the driving feedback unit was modified with an harmonic number of 3×80. The drive scheme applied for bunch excitation was then chosen to kick only every third turn or to pause every third turn. This way, one island is less excited and the sum of all drift rates will generate a particle stream to that island. Which scheme is more effective depends on the horizontal displacement of the islands with respect to the kicker.

The black graph in Fig. 3 shows a tune spectrum corresponding to population of a single island at the MLS. A kick-kick-pause scheme has turned out to be the most effective one. A strong signal is visible at $\Delta Q_x = 1/3$, in contrast to all other spectra. The reason is the difference between the coherent motion of all electrons in one island "jumping" from fixed point to fixed point and equally populated islands exchanging places.

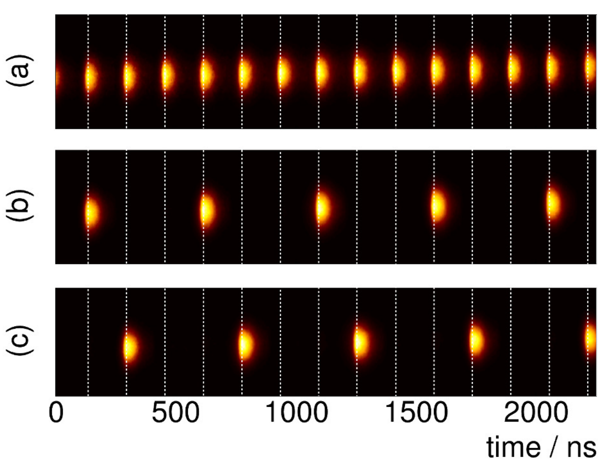

Figure 4: Down-conversion of repetition rate near $\Delta Q_x = 1/3$: Streak camera measurements are shown for single bunch operation with resonance island buckets. Equally populated islands (a) are characterized by a repetition rates of $f_{rev} = 6.25$ MHz in contrast to a single populated island with $f_{rev}/3 = 2.08$ MHz (b and c). Dashed lines mark revolution harmonics with a spacing of 160 ns.

Figure 4 shows streak camera measurements obtained from operating a single bunch stored in island buckets. The streak camera was set up at the undulator beamline. The aperture of the photon beamline was modified to transmit radiation of a single island only. Figure 4 (a) shows a state where the particles are equally distributed in the islands – corresponding to the red plot in Fig. 3. Single island population according to the proposed scheme is shown in Fig. 4 (b). Within seconds and without further tuning it is possible to redistribute electrons to another island, i.e. shifted by one revolution time – Fig. 4 (c). where the stable island was shifted by one revolution from (b) to (c). Revolution down-conversion of ID radiation pulses was successful with a signal to noise purity of about 100.

CONCLUSION & OUTLOOK

Resonance island buckets have been stably applied for operation at the MLS. The achieved performance and reproducability is in the order of standard user operation. Photon beam separation was shown for bending magnet and insertion device radiation. Down-conversion of the revolution time by a factor of 3 was shown for radiation pulses generated by a single bunch in an insertion device. First user shifts to apply this mode of operation for time-of-flight spectroscopy are already scheduled.

The experimental experience gained at the MLS is now in the process of being transferred to BESSY II. There, resonance island buckets may serve as means of beam separation for complex filling patterns which are required by the BESSY VSR project [5].

ACKNOWLEDGMENT

This work was excellently supported by our HZB and PTB colleagues – in particular Klaus Ludwig (HZB), Arne Hoehl, Hendrik Kaser, Michael Kolbe and Mathias Richter (PTB). It is a pleasure to thank Massimo Giovannozzi (CERN) and Andrea Franchi (ESRF) for very fruitful discussion and a hadron point of view as well as Dmitry Teytelman for helping to modify the feedback system.

REFERENCES

[1] J. Feikes et al., "Metrology Light Source: The first electron storage ring optimized for generating coherent THz radiation" Phys. Rev. ST Accel. Beams 14, 030705 (2011). http://journals.aps.org/prstab/abstract/10.1103/PhysRevSTAB.14.030705

[2] M. Ries, "Nonlinear momentum compaction and coherent synchrotron radiation at the Metrology Light Source – low-alpha commissioning and development", PhD thesis, Humboldt-Universität zu Berlin, Germany 2014, http://edoc.hu-berlin.de/dissertationen/ries-markus-2014-05-12

[3] C. J. A. Corsten, "Resonance and Coupling Effects in Circular Accelerators" PhD thesis, Eindhoven University of Technology, 1982, http://repository.tue.nl/131701

[4] R. Cappi and M. Giovannozzi, "Multiturn extraction and injection by means of adiabatic capture in stable islands of phase space" Phys. Rev. ST Accel. Beams 7, 024001 (2004). http://journals.aps.org/prstab/abstract/10.1103/PhysRevSTAB.7.024001

[5] A. Jankowiak, J. Knobloch, P. Goslawski, N. Neumann, editors, "BESSY VSR – Technical Design Study", Helmholtz-Zentrum Berlin, 2015, to be published,

[6] A. Schälicke et al., "Status and Performance of Bunch-By-Bunch Feedback at BESSY II and MLS", IPAC'14, Dresden, Germany 2014, TUPRI072 (2014).