Two Orbit Operation at BESSY II during a User Test Week

Transverse Resonance Island Buckets at BESSY II and its User Application

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19th - 24th May 2019
10th IPAC2019, Melbourne, Australia
Overview

- **Transverse Resonance Island Buckets**
  
  **TRIBs** at HZB, i.e., at BESSY II (and MLS)
  
  - Definition, Studies, Experiments, Application, Outlook

- **Motivation**
  
  - Why TRIBs at BESSY II / VSR (and MLS - Metrology Light Source)?
    - TRIBs for DLSR?

**BESSY II:**

1.7 GeV, 240 m, DBA, 5 nm rad

Soft X-ray, **Spectroscopy**, **Timing**

**MLS, Metrology Light Source:**

630 MeV, 48 m, DBA, 100 nm rad

VUV, EUV, THz, low (negative) α
TRIBs - Additional Stable Fixed Points

Application: multiturn extraction


No Application at Light Sources so far

- Do not store beam on resonance
- “Accelerator operators are keen to avoid low order strong resonances because of visibly short lifetime.”
- “Accelerator physicists are eager to apply their skill to correct or compensate the resonance for minimizing their effects on the beams.”

 Accelerator Physics, S.Y. Lee


FIG. 14. Synchrotron radiation image of the beam near the $3\nu_c$ resonance. Left is the situation before the optic is corrected and right is the situation after the optic is corrected. (The plane of the camera is rotated with respect to the plane of the beam.) Also there is a distortion in the light optic in the vertical plane that is responsible for the image’s vertical asymmetry.
TRIBs - Not new

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“Multiturn extraction and injection by means of adiabatic capture in stable islands of phase space”,

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“Realizing the benefits of restored periodicity in the advanced light source”

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R.Cappi and M.Giovannozzi,

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Tree felled by family Kuske

FIG. 14. Synchrotron radiation image of the beam near the $3\nu_s$ resonance. Left is the situation before the optic is corrected and right is the situation after the optic is corrected. (The plane of the camera is rotated with respect to the plane of the beam.) Also there is a distortion in the light optic in the vertical plane that is responsible for the image’s vertical asymmetry.
Transverse Resonance Island Buckets - TRIBs - at BESSY II

- Operating machine close to horizontal 3rd order resonance
- Tackle non-linear beam dynamics
- Minor impact on linear beam optics expected

2nd stable fix point & orbit

- BESSY II standard setting
- BESSY II TRIBs at 3rd order resonance

BESSY II working point (17.85, 6.73)
BESSY II TRIBs at 3rd order (17.66, 6.73)
Application: A new electron bunch separation scheme

2nd stable orbit with Transverse Resonance Island Buckets - TRIBs

Aim: Multiple beam storage with island buckets
Application: A new electron bunch separation scheme

2\textsuperscript{nd} stable orbit with Transverse Resonance Island Buckets - TRIBs

3\textsuperscript{rd} order resonance  
Island orbit closes  
after 3 turns

Two stable independent orbits  
capable to store  
two independent fill pattern
Application: A new electron bunch separation scheme

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Application: “Increase Revolution Time”

2\textsuperscript{nd} stable orbit with Transverse Resonance Island Buckets - TRIBs

3\textsuperscript{rd} order resonance
Island orbit closes after 3 turns

Increasing revolution time, decreasing revolution frequency
- By the factor = order of resonance
- Decreasing repetition rate at small storage rings for TOF exp.
- **Proof-of-principle User Experiment at the MLS**
  (see T. Arion et. al., Rev. Sci. Instrum. 89, 103114 (2018))

Streak camera with aperture to select photons of one island
TRIBs: Fill pattern manipulation

Fill pattern (or current) manipulation and tunes

- Electrons can be shuffled between both orbits without losses (video)

![Core and island orbit populated](image1)

![Island orbit populated](image2)

![Core orbit populated](image3)

- Core and island orbit populated
- Only core orbit populated
- Only island orbit populated
- Only one island populated

Arbitrary fill pattern within seconds

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P. Goslawski, TRIBs at BESSY II

10th IPAC 2019, Melbourne, Australia
Motivation: Provide best Radiation, simultaneously!

Standard Multi Bunch Hybrid Fill Pattern at BESSY II

In addition:
- Single Bunch mode 2-3 weeks per year … 1.25 MHz
- Few Bunch mode 2-3 days per year … 5 – 10 MHz
- Low alpha mode 2 weeks per year

See – https://www.helmholtz-berlin.de/quellen/bessy/betrieb-beschleuniger/betriebsmoeglichkeiten_en.html or google: BESSY II operation modi

Bunch Separation Scheme for Gap Less Operation

DLSRs, BESSY VSR…
Proof-of-principle experiments

- Island operation compatible with
  - High current operation (300 mA)
  - IDs: moving undulator gaps and SC devices (7T MPW)

- **Separation - good enough?**
  Electron separation --> Photon pulse separation?
  - Beam parameters: orbit stability, emittance, ...
  - Align island orbit on bend/ID beam line, selecting source spot
  - Purity, diffusion rates, SNR
  - Usable at all beam lines at the same time?
  - Impact of radiation from island orbit on standard orbit?

- **Injection - TopUp operation possible?**
  - Injection Efficiency (>90%) and Lifetime (>5h@300mA)?
  - Injection Scheme
Common experiments with beam line scientists and in-house users

K. Holldack, F. Kronast, R. Ovsyannikov, E. Schierle, G. Schiwietz

Successful separation at bending magnet and undulator beam lines

Achieved purity: > 100, > 1000 depending on beamline

4 ID beam lines (UE56-1, UE112, UE49, UE46)
UE56-1 ZPM, 831 eV linear vertical polarized

Bending magnet beamline (PM4)
Source point mapped by 1st mirror scan

K.Holldack, F.Kronast, R.Ovsyannikov, E.Schierle, G.Schiwietz

Achieved purity: > 100, > 1000 depending on beamline

UE56-1 ZPM, 1333 eV, elliptical polarized mode
Separation – Orbit Displacement and Angle for 2\textsuperscript{nd} Island Orbit

Separation: > 10\sigma at horizontal source size of \(\sigma_x \sim 300\,\text{mm}\) and divergence of maximal \(\sigma'_x \sim 0.3\,\text{m rad}\)
TRIBs at BESSY II: Optical Functions & Emittance

Emittances:
- B2 standard user mode: 7.6 nm rad
- B2 TRIBs core orbit: 7.7 nm rad
- B2 TRIBs island orbit: 8.0 - 14 nm rad

\[ \sigma = \sqrt{\beta \cdot \epsilon + (D \cdot \delta)^2} \]

Source size on island orbit increases by a factor of < 2
TRIBs at BESSY II: TopUp Injection

TopUp injection conditions for user operation

- Average injection efficiency > 90 %
- Shot by shot injection efficiency > 60 %
- Lifetime > 5 h @ 300 mA
- Stable user conditions over night !!

TRIBs feasible with TopUp injection and many closed IDs

![Graph showing injection efficiency and TRIBs signal over time]

- Change to TRIBs optics and some optimisation with beamline scientists
- Successful 8h over night run

- Current
- Injection Efficiency
- TRIBs Signal
TRIBs move towards realistic User Operation

TRIBs/Two Orbit Test Week – February 2018

- Verify if beam quality for realistic user operation mode is reached in terms of
  - Electron orbit, i.e., photon signal stability
  - Simultaneous use of multiple IDs
  - Injection efficiency and lifetime (TopUp)
- Verify that multi bunch signal from standard orbit is not disturbed by the island orbit signal
- Increase accessibility of the island orbit at beam lines

- Demanding daily schedule:
  07-10h: Storage ring optimisation
  10-16h: Common experiments
  16-18h: Restoring TRIBs for
  18-07h: TRIBs User Run

- 13 User feedbacks
  … Great response!

19th - 25th February 2018

Open beam shutters / beam lines

20/39, 23.02.2018, Friday 13:00

Legend: open moving closed
TRIBs at BESSY II: Two Orbit User Test Week
CW08, 19th-25th February 2018

TRIBs/Two Orbit Test Week: Summary, Conclusions, Next steps and Outlook

- Two Orbit User Test week report online (see VSR homepage)
  - Feedback helps to develop realistic user operation mode

- **Timing Users: D2, U125** (example)
  “we succeed to adjust our microscope finally. Everything works nice. We have a 1000:1 signal to multibunch ratio in intensity. Absolutely great, we can measure in this mode without problems.”

- **Multibunch Users:**
  Taking injection not into account, TRIBs behaves at beamlines with good selection opportunities (flexible apertures, intermediate focus) like the Standard User setting. Injection is a problem since the source changes; Normalisation of data on beam current difficult

1) Technical topics: Adapt all systems to two orbits!
   (Orbit feedback control, ID compensation, orbit bumps, additional apertures at beamlines, ...)

2) Last big conceptual challenge: **TopUp-Injection process**
   - Repopulation of orbits for injection disturbs the signal from standard orbit for too long time
   - Reduce disturbance or inject directly on island orbit

TRIBs tested successfully in TopUp User Operation
Injection into BESSY II’s TRIBs optics

- Using classical 4-kicker injection scheme; all current injected on main orbit!
- Therefore all current from island orbit is pushed to main orbit using bunch resolved tune excitation. This bucket cleaning stays on for the whole injection process to force injected charge to move directly on main orbit, this disturbs the main orbit.
- After injection the current increase in BESSY II is measured (this takes up to 2-3 seconds) and then afterwards
- Single Bunch or Few Bunch is pushed back to island orbit

Classical 4-kicker injection on main orbit

- Collapsing all current to main orbit
- Excitation on all bunches, TRIBs Tune
- Disturbing main orbit signal!

- 5 s
- 0 s
- + 3 s

8 seconds of main orbit disturbance
TRIBs (near) Future

Pushing towards realistic user operation & understanding

- HZB pushes TRIBs towards a user operation state; TopUp Injection at BESSY II and feasibility studies for successor - BESSY III

- Study Group, Collaborators? TRIBs at other facilities – **TU Dortmund/DELTA, MAX IV Laboratory**! Many open questions at this non-linear two beam dynamic regime: horizontal, vertical islands, trans.-long. coupling, diffusion rates, potential-well depth, lattice design for TRIBs, etc.

- New Verbundforschungsantrag (2019 – 2022) – **TiMo: Timing Modes for Advanced Light Sources** **PhD positions** – If interested --> paul.goslawski@helmholtz-berlin.de

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**Next TRIBs User Week**
**Spring 2020**
Summary: TRIBs at HZB

Proof-of-Principles Experiments done!

- **Separation scheme**, two stable orbits in one machine, 2nd fill pattern stored on 2nd orbit tailored for timing experiments (average brightness and timing: repetition rate and short bunches)

- Multi-Bunch fill on standard orbit and Single Bunch or Few Bunch Filling on island orbit

- Studies towards user operation in a 3rd generation light source, combine with TopUp injection scheme, many IDs (BESSY II / VSR) together with DELTA/TU Dortmund and MAX IV general understanding

TRIBs for

1) BESSY II
2) BESSY VSR
3) BESSY III
4) ... others?

**BESSY VSR**

Helmholtz-Zentrum Berlin will provide long and short intense bunches simultaneously → pulse separation mandatory

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Fall 2015 see news HZB and lightsource.org

Spring 2018 see news HZB and lightsource.org
Thank you for your attention

Thanks to all internal and external Colleagues & Users contributing to TRIBs
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Team

Accelerator group:
Felix Armborst (Kramer), T. Atkinson, J. Feikes, P. Goslawski,
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K. Holldack, F. Kronast, R. Ovsyannikov, E. Schierle, G. Schönhense

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