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CHARACTERISATION OF THE SECOND STABLE ORBIT GENERATED BY TRANSVERSE RESONANCE ISLAND BUCKETS (TRIBs)*

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Abstract

Operating the storage ring near a transverse tune resonance [1–3] can generate TRIBs in the corresponding phase space, providing a second orbit twisting around the standard orbit. TRIBs as a bunch separation scheme in combination with the proposed variable bunch length storage ring BESSY VSR [4] represent a promising alternative to dedicated single or few bunch operation modes. The injection efficiency and stability of the two orbits at BESSY II and MLS are almost on par with and the lifetime at about 70 % of the standard user mode. Results from simulations and measurements of our present island optics will be presented. Beam parameters like the betatron motion, dispersion and emittance of both the core and island orbit will be discussed as well as the separation between the island and the core orbit. At BESSY II a dedicated test week together with the friendly users took place in the first week of February, 2018.

INTRODUCTION

The user community of light sources is separable into two main groups: those interested in static properties of their probes, requiring high average brilliance or flux (e.g. diffraction, scattering, microscopy experiments) and those interested in dynamic properties performing time resolved experiments, requiring a special time structure of the light (e.g. pump-probe, time-of-flight experiments). At BESSY II both of these diverging user requirements are served by offering low-α optics, a single bunch and since 2017 also a few bunch mode [5–7]. These dedicated optics and fill patterns are only offered a few weeks per year. Inclusion of special bunches in the standard fill pattern with photon separation by a mechanical chopper [8], pulse picking by resonant excitation (PPRE) [9] or in the slicing facility [10] provide the possibility of meeting divergent user demands simultaneously. A second stable orbit as generated by TRIBs with its intrinsic separation for every bunch provides the possibility of beam spot selection by adjustment of the beamline without the need for additional bunch separation mechanisms and their disadvantages (e.g. chopper dark gap 200 ns). With the proposed upgrade BESSY VSR even different bunch lengths will be available simultaneously. Here TRIBs could provide the possibility to separate all short and long bunches. In the week of February 19th this year a successful friendly user test week with TRIBs optics was performed at BESSY II. The daytime was used for joint experiments with users while availability and stability were prioritized for the night shifts. The general feedback concerning the usability of the island orbit and the stability of the island core in comparison to the standard user mode was very positive. The injection process with multiple seconds of collapsed island orbit and some disturbance on the core orbit provides the highest potential for optimization [1].

BESSY II TRIBS OPTICS

The BESSY II TRIBs linear optics as shown in Fig. 1 are obtained from a measurement of the closed orbit response matrix (LOCO) of the core orbit. The nonlinear optics are taken from the measured currents in the sextupole magnets and their conversion factors. The obtained nonlinear optics are verified with measurements of nonlinear observables such as the chromaticity, the tune shift with amplitude (TSWA), the beam sizes and the orbit separation as a function of the core tune.

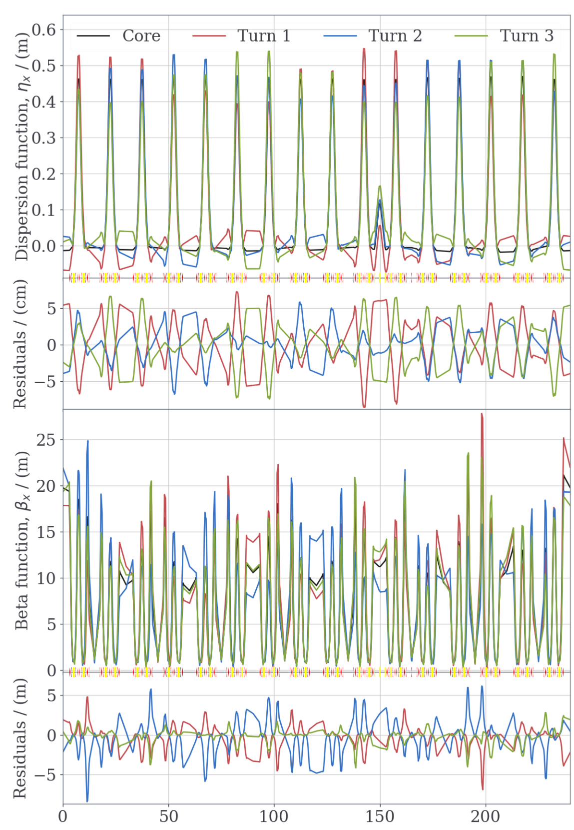

Figure 1: Dispersion and betatron function of the BESSY II TRIBs optics and the residuals to the core orbit. [11, 12]

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Separation

For the test week with friendly users the expected spatial and angular separation of the core and island orbit at all insertion devices and dipole beam lines were simulated from the TRIBs optics. This gave the users the orientation to consciously select the island orbit with their beamline. The island and core beam are well separated at all source points of the insertion devices in either position or angle. Figure 2 exemplarily shows the separation for all straights: the high-β doublet straights provide high spatial separation in the order of 4 mm while the low-β triplet straights provide good angular separation in the order of 2 mrad.

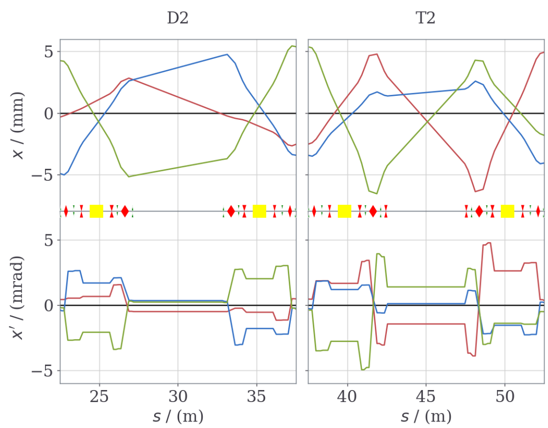

Figure 2: Exemplary spatial and angular separation of the island orbit in a triplet and doublet section. [11, 12]

Phase Space

A comparison of the x-x'-phase space of the standard user and TRIBs optics as shown in Fig. 3 highlights the smaller dynamic aperture of the current TRIBs optics - especially when only considering the core orbit. Even though the dynamic aperture of this TRIBs optics is not yet optimized, the challenging radiation safety requirements [1] for top up injection at BESSY II were achieved. This years TRIBs test week was completed with an availability of 99.78 % [14] and has proven that these requirements can be met - even over an entire week of user operation. Slight adjustments to the injection and precise control of the beam optics to compensate for the current dependency of the tune when filling the storage ring were required.

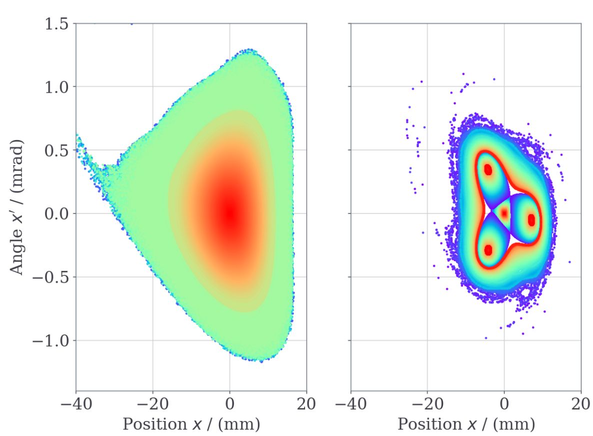

Figure 3: Horizontal phase space of the LOCO measured BESSY II standard user and TRIBs optics showing the proportions of their dynamic apertures. The particles are colored according to their initial position. [11–13]

Tune Shift with Amplitude (TSWA)

The simulated horizontal TSWA for the standard user optics as shown in Fig. 4 is about 2.2 kHz mm^{-1}mrad^{-1}. Measurements of the standard user optics TSWA [1, 15] are in good agreement with this value. The TSWA is not only a global observable for the nonlinear optics but also in accordance with the core tune the determinant of the position of the island orbit. Therefore a precise measurement and correction of the core orbit tune and the TSWA is required to maintain a stable position of the island orbit during user operation. To achieve this goal in the test week a dedicated bunch-by-bunch feedback (BBFB) unit [16, 17] was used for a phase locked loop tune measurement on a single core bunch to provide a reliable tune measurement for the tune feedback system which then kept the core tune and thus the position of the island orbit stable. This setup proved to be sufficient in order to achieve good stability of the island orbit [18]. The impact of the insertion devices on the nonlinear optics in general and specifically on the TSWA proved to be negligible in our case.

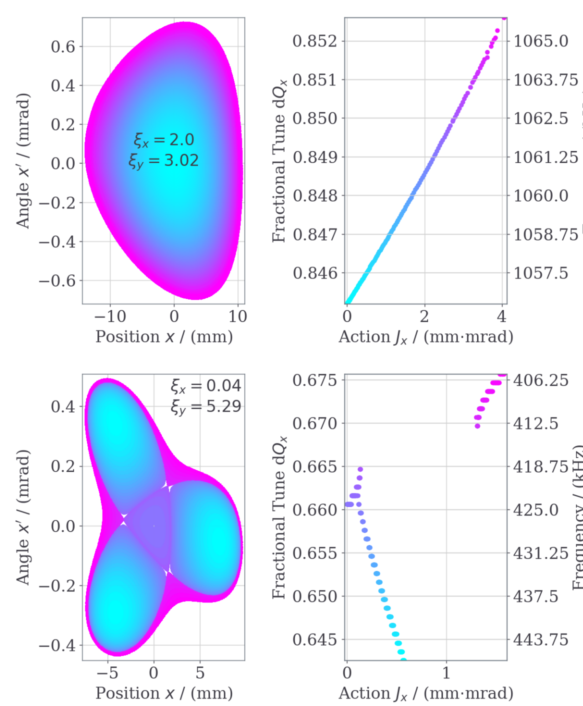

Figure 4: The TSWA for the BESSY II Standard User (upper plot) and the BESSY II TRIBs (lower plot) optics from transverse tracking simulations. The impact of chromaticity and energy spread is not included. [11–13]

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Core and Island Emittance

While the nonzero residual betatron oscillation (Fig. 1) suggests a change in the emittance of the island orbit, the residual dispersion hints at an increase. Closed orbit simulations of the island orbit confirm an increased emittance of the island orbit in comparison to the core orbit (reference orbit of the core beam). Investigation of the island emittance further show a dependence on the tune of the core orbit (Fig. 5). Due to the fixed TSWA the maximum separation of the core and island orbits also depend heavily on the core tune.

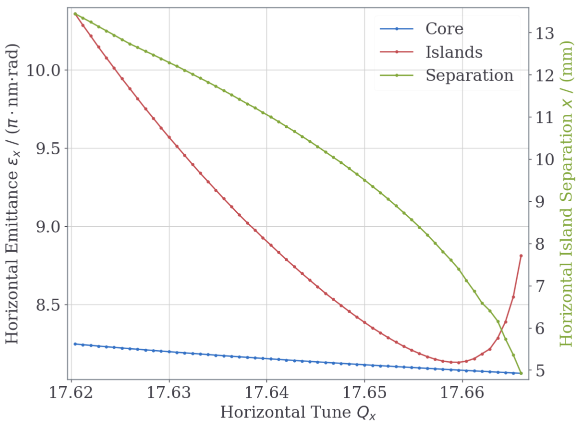

Figure 5: Emittance of the island (red) and core (blue) obits as a function of the core tune. The maximum separation of the island and core orbits over the entire ring (green) is determined from the core tune and the TSWA. [11, 12]

To experimentally verify this feature the horizontal beam size of the island orbit was measured as a function of the core tune. Figure 6 shows the results of the simulated horizontal beam size and separation at the pinhole monitor. The measured beam size for the first turn of the island orbit or one spot on the pinhole monitor as a function of the core tune is included (upper left subplot). While reproducing the expected beam sizes in the order of a few percent for core tunes far from resonance, the expected minimum of the horizontal island beam size is shifted. The feature of a minimal emittance ratio between core and island orbit just before the core tune reaches the resonance is observed at a greater distance from the resonance in comparison to the the simulation. The measured shift in the resonance line indicates further nonlinear (e.g. coupling, collective effects) tune shifting effects for the island orbit. Considering the neglection of any longitudinal dynamics (e.g. chromaticity, energy spread, cavity) in the simulations even though these are known to have an impact on the tune the observed accordance is astonishing.

CONCLUSION

The BESSY II TRIBs optics show an astoundingly good agreement with measured nonlinear observables. Especially when considering the simple procedure to measure the optics

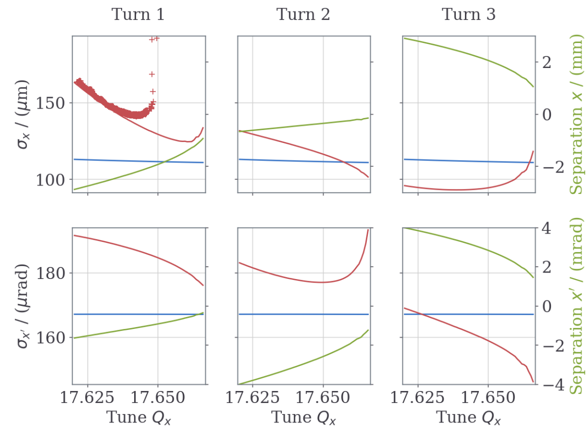

Figure 6: Thes plots show the core (blue line) and island (red line) beam size as well as the separation (green line) of the two for each turn (or spot) of the island orbit at the position of a pinhole monitor as a function of the core tune. The measured Beam size (red crosses, upper left subplot) of the first island shows similar behavior as the simulated. The Position of the minimum differs and needs to be investigated further. [11, 12]

and the heavy dependence of the TRIBs optics on the nonlinearities of the lattice. For future simulations the longitudinal effects also need to be taken into account. The impact of the combination of chromaticity and energy spread on the tune and thus the island orbit properties is expected to be significant and will therefore be a main subject of future investigations.

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