**TUNE AND CHROMATICITY OPTIMIZATION AT BESSY II FOR THE TRANSVERSE RESONANT ISLAND BUCKET OPTICS**

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Abstract

The exploitation possibilities for stable Transverse Resonant Island Buckets (TRIBs) are under investigation at the third generation light source BESSY II in Berlin. At BESSY II TRIBs on a 3rd order horizontal resonance are used to enable a second stable orbit, longitudinally winding around the core orbit in the transverse \(x-x'\)-phase space. The applicability for bunch separation is a main subject of these studies. Photons emitted on the second orbit are well separated from those of the main orbit at all beamlines. This provides the possibility of bunch separation by beamline adjustment for the timing community without significant impact on the average brightness for other users. Simulations based on linear optics from closed orbits (LOCO) and nonlinear optics derived from the measured chromaticity and tune shift with amplitude (TSWA) predict this separation well. Stable operation of the TRIBs optics at BESSY II has been demonstrated with friendly user experiments in 2018 also confirming the separation simulations predicted. BESSY VSR, the next major and scheduled upgrade project at BESSY II features simultaneously stored long and short bunches. The TRIBs optics would in principle then enable the separation of the different bunch lengths at every beamline offering unique possibilities to the user community. Simulations and measurements aiming to investigate further possible optimizations of the TRIBs optics are presented.

**INTRODUCTION**

At BESSY II, TRIBs [1, 2] and the possibilities of optimization and quantification of the according optics are under investigation aiming for a new user operation mode possibly in combination with the scheduled upgrade BESSY VSR [3]. As previously presented simulation studies [1] show, the emittance reduction possibilities for the second orbit by changing the core tune are promising. In this paper measurements of this correlation will be presented and compared to our simulations. Furthermore simulations and corresponding measurements concerning the second orbit optimisation by changing the core chromaticity are presented. The general limits concerning the chromaticity for the TRIBs optics at BESSY II will be given.

**PINHOLE MEASUREMENTS**

Due to the diffraction limit for low photon energies the synchrotron radiation monitors at BESSY II, the pinhole systems [4], use high energy X-ray photons with a mean energy of 16 keV. These photons are filtered from the dipole radiation and imaged through an array of 11x21 pinholes of 20 \(\mu\)m diameter onto a CCD as shown in Fig. 1.

![Image](image_url)

**Figure 1:** Image at pinhole 9 with TRIBs optics and all current on the second orbit. Three spots correspond to one pinhole. Coupling [5] gives vertical separation of the beam spots for the horizontal resonance. The ROI’s are found in order of the peak height and numbered accordingly. [6]

Hereby each pinhole of the array can be treated as a conventional pinhole camera. For TRIBs optics experiments it is beneficial to remove the filter in order to get sufficient amounts of light on the screen allowing shorter exposure times and live imaging of the island population. This is crucial in order to easily optimize the tune and chromaticity for stable TRIBs and the bunch by bunch feedback (BBFB) [7] settings for fast active population and depopulation of the orbits. The beam size measurements presented in this paper were also performed without the high energy photon filter. Thus, also using the light of the low energy photons enabling shorter exposure times at the cost of resolution. Figure 1 shows the complete image from one of two available pinhole systems at BESSY II. The image in Fig. 1 was taken using TRIBs optics and with all electrons on the second orbit. Therefore 3 spots correspond to one pinhole. Before an evaluation of the individual spot sizes is possible outlier pixels need to be eliminated and regions of interest (ROI) for each spot defined. Then for the beam size measurement a bivariate normal distribution as in Eq. (1) is fitted to each spot.

\[
f(x, y) = \frac{\Lambda}{2\pi \sigma_x \sigma_y} e^{-\left(a + b + c\right)/2} + o \tag{1}
\]

\[
a = \left(\frac{\cos^2(\theta)}{\sigma_\theta^2_x} + \frac{\sin^2(\theta)}{\sigma_\theta^2_y}\right) (x - \mu_x)^2 \tag{2}
\]
for natural diffusion into the TRIBs orbit. Thus the active population with the BBFB was only used for fast initial population and depopulation of the TRIBs orbit. During the measurement only a small broadband vertical excitation was applied for the tune measurement. The measured beam size $\sigma_x$ and separation is compared to the simulation shown in Fig. 3.

![Figure 3: The simulated (red lines) and measured (red dots) transverse beam sizes $\sigma_x$ at Pinhole 9 as a function of the fractional horizontal core tune $dQ_{x,core}$ together with the corresponding separation (green). The simulation is based on our measured linear optics from closed orbits and nonlinear optics fitted to match the chromaticity and tune shift with amplitude measured at the machine in 2018. [6,9]](image)

While they qualitatively correspond to the simulations showing the same slopes and extrema the resolution limit of the pinhole without the filter is too high for a quantitative comparison. The shown separation is based on a vague approximation of the core position as the center of mass of the island beam spots. It corresponds in slope and approximate position to the simulated separation considering the imprecision of this approximation.

### CHROMATICITY OPTIMIZATION

When taking the longitudinal beam dynamics, e.g. cavity and synchrotron radiation into account in simulations, the chromaticity becomes an important parameter. Due to the chromaticity and the chromatic tune shift the transverse position of a fixed point becomes a function of the energy. Thus the chromaticity translates the natural energy spread of the electrons into a tunespread which again translates into a spread of the corresponding fixed point and thus a smearing out of the trajectories in the transverse phase space. Simulations with two particles with identical transverse initial parameters but different energies show this effect as a blowup of the transverse phase space for high chromaticities as shown in Fig. 4. Averaging the Euclidean distance for the core and the island orbit between the two $\delta = \pm 1$% particles in the $x - x'$-phase space over 1000 tracked turns for different chromaticities $\xi_x$ as shown in Fig. 5 indicates a dependence of the stability on the chromaticity. It clearly shows
an increased dependence for the island particles. The jump to an instable regime at high chromaticities comes earlier for the island particles. The maximum stability is reached at a chromaticity \( \xi x \) close to 0.

The Measurement of the beam size as a function of the horizontal core chromaticity (Fig. 5) shows a minimum at \( \xi x = 0 \). The beam size is then strongly increased in both planes for higher chromaticity as shown in Fig. 6. For \(|\xi| > 3\) the islands become instable at the machine. This observation fits well with the step in Fig. 5.

**OUTLOOK - TSWA OPTIMIZATION**

The location of the stable fixed points in the transverse phase space is determined by the combination of the core tune (linear optics), the chromaticity \( \xi x \) and corresponding tune shift and the TSWA. The TSWA has thus already been the subject of former studies \([1,2]\). So, whilst having been investigated as one of the fundamental driving principles for TRIBs in general, the optimization of the tune shift with action in respect to the island orbit may well be a key parameter for optimizing the stability as well as the diffusion to and from the island orbit. The total tune shift with action in respect to the island orbit being the difference of the outermost island particle tune and the innermost reflects the tune spread of the island orbit and thus can be seen as a measure of it’s stability or tune acceptance.

**ACKNOWLEDGEMENTS**

I gladly acknowledge the helpful discussions and support of many colleagues at HZB, especially M. Ries, A. Schälicke, M. Koopmans and everybody I forgot.

**CONCLUSION**

The emittance modification possibilities by optimization of tune and chromaticity predicted by simulations are qualitatively confirmed by the presented measurements. The extrema and slopes of the simulations are also observed in the measured data. The separation at the minimum emittance tune is promising for user experiments. Also the chromaticity must be minimized for stable island operation. Simulations and general considerations imply a strict requirement of minimal chromaticity to stop the natural energy spread from translating into a tune spread and thus forcing off-energy particles to diverge from the island orbit of the reference particle. This behaviour is also observed at the machine where increasing the chromaticity leads to higher diffusion rates into the core and eventually a breakdown of the second stable orbit.

**REFERENCES**


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