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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 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 possiblities 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 µm diameter onto a CCD as shown in Fig. 1.

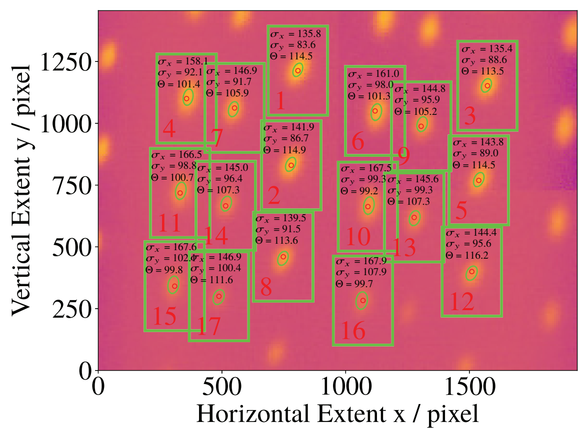

Figure 1: Image at pinhole 9 with TRIBs optics and all current on the second orbit. Three spots correspond to one pinhole. Coupling [5] gives vertical separation of the beam spots for the horizontal resonance. The ROI's are found in order of the peak height and numbered accordingly. [6]

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 eposure 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 spotsizes 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.

$$f(x, y) = \frac{\Lambda}{2\pi\sigma_x\sigma_y} e^{-(a+b+c)/2} + o \quad (1)$$

$$a = \left(\frac{\cos^2(\theta)}{\sigma_x^2} + \frac{\sin^2(\theta)}{\sigma_y^2}\right)(x - \mu_x)^2 \quad (2)$$

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$$b = \frac{\sin(2\theta)}{2}\left(\frac{1}{\sigma_y^2} - \frac{1}{\sigma_x^2}\right)(x-\mu_x)(y-\mu_y) \quad (3)$$

$$c = \left(\frac{\sin^2(\theta)}{\sigma_x^2} + \frac{\cos^2(\theta)}{\sigma_y^2}\right)(y-\mu_y)^2 \quad (4)$$

This corresponds to a 2D Gaussian function centered at the expected values (μ_x, μ_y) with standard deviations (σ_x, σ_y), Amplitude Λ, arbitrary background o and rotated by θ as shown in Fig. 2. The accuracy of the initial values is crucial for the convergence of the fit. The initial background o is given by 2D interpolation of linear fits to the edges of the ROI. The initial amplitude Λ is retrieved from numerical integration of the background corrected data. The expected values, standard deviations and the angle of rotation can be estimated from the ellipse given by the intersection of the data with a horizontal plane at half peak height. As the ROI's are found in order of the peak magnitude (see Fig. 1), resorting from left to right and top to bottom is necessary for evaluation of the beam spots over many measurments or over a parameter scan as presented further on.

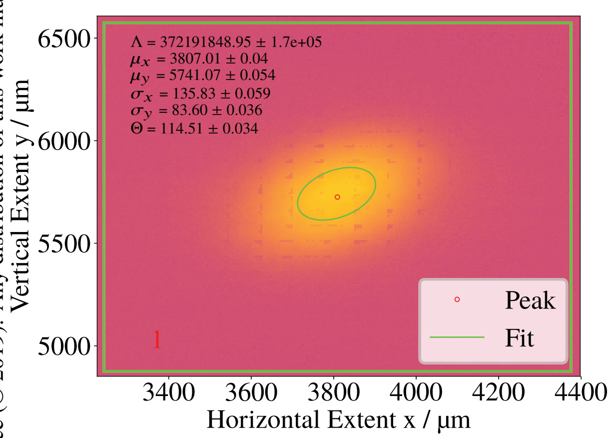

Figure 2: Exemplary fit of a 2D rotated Gaussian function to the beam spot in ROI 1 in Fig. 1. [6]

TUNE OPTIMIZATION

Previous simulations [1] have shown the possibility of modifying the island emittance by tune optimization with sufficient separation. A first measurement was performed using the beam size extracted from the x-projection of one large ROI, in which one beam spot of the TRIBs orbit remained for the entire tune scan. Whilst this showed good agreement with the simulated beam size, the other beam spots and thus also the separation were not available. Using the multi-ROI technique described before, the simultaneous measurement of the beam spot parameters of each pinhole is possible. The tune spectrum was measured with the BESSY II Beam Motion Monitor [8]. This system measures the full beam spectrum at two diagonally fixed striplines optimized to enable supression of the main RF signal. For the measurement of the beam size as a function of the tune, the chromaticity (chromatic sextupoles) and tune shift with amplitude (harmonic sextupoles) were optimized beforehand 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 σ_x and separation is compared to the simulation shown in Fig. 3.

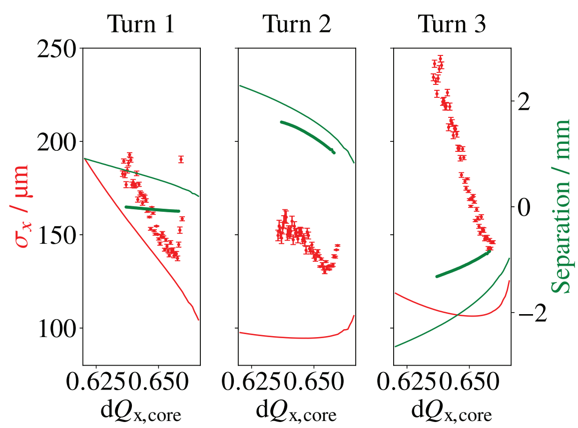

Figure 3: The simulated (red lines) and measured (red dots) transverse beam sizes σ_x at Pinhole 9 as a function of the fractional horizontal core tune $dQ_{\mathrm{x,core}}$ together with the corresponding separation (green). The simulation is based on our measured linear optics from closed orbits and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

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 paramenter. 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 ξ_x as shown in Fig. 5 indicates a dependence of the stability on the chromaticity. It clearly shows

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an increased dependence for the island particles. The jump to an instable regime at high chromaticites comes earlier for the island particles. The maximum stability is reached at a chromaticity ξ_x close to 0.

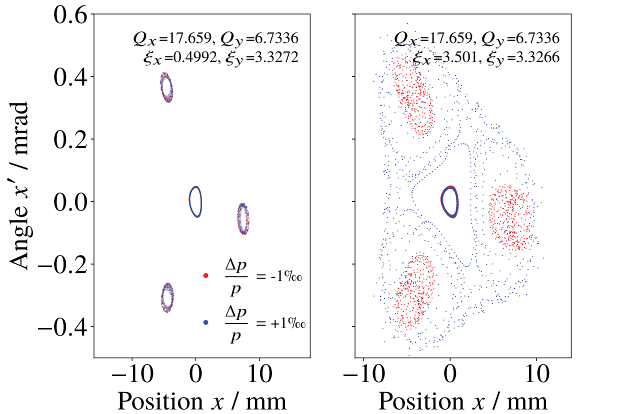

Figure 4: Trajecory of particles with initially identical transverse coordinates (x, x') but different initial momenta ($\delta = \pm 1$ ‰) at $\xi_x = 0.5$ (left) and $\xi_x = 3.5$ (right) over 1000 revolutions. [6,9]

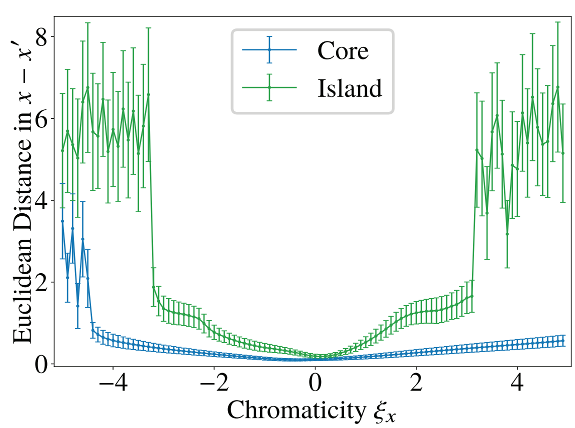

Figure 5: Euclidean distance between two particles with identical transverse starting coordinates but different momenta averaged over 1000 turns as shown in Fig. 4 as a function of the horizontal core chromaticity ξ_x. [6,9]

The Measurement of the beam size as a function of the horizontal 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 $|\xi_x| > 3$ 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 $x - x'$ phase space is determined by the combination of the core tune (linear optics), the chromaticity ξ_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

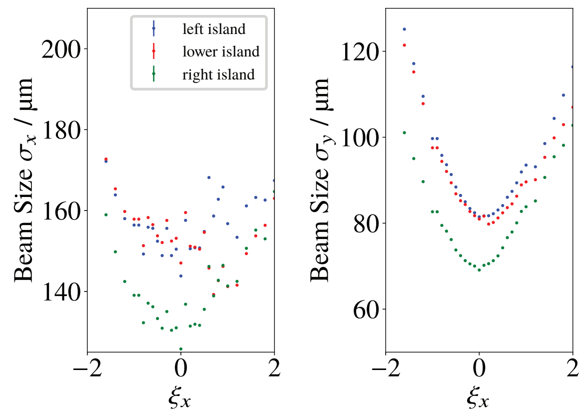

Figure 6: Transverse beam size measured at pinhole 9 as a function of the horizontal core chromaticity. The intermediate steps of the chromaticity rely on the accuracy of the BESSY II chromaticity bump. It was also meausured directly at the beginning and end of the scan. [6]

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.

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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 obsered 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

[1] F. Armborst *et al.*, “Characteristion of the second Stable Orbit Generated by Transverse Resonance Island Buckets (TRIBs)”, in *Proc. IPAC'18*, Vancouver, Canada, paper TUPML052, pp. 1656–1659.

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[2] P. Goslawski *et al.*, “Status of Transverse Resonance Island Buckets (TRIBs) as Bunch Separation Scheme”, in *Proc. IPAC’17*, Kopenhagen, Denmark, paper WEPIK057, pp. 3059–3062.

[3] A. Jankowiak *et al.*, Eds., “BESSY VSR – Technical Design Study”, Helmholtz-Zentrum Berlin für Materialien und Energie GmbH, Germany, June 2015. DOI: 10.5442/R0001.

[4] K. Holldack, J. Feikes, W.B. Peatman, “Source size and emittance monitoring on BESSY II”, in *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, vol. 467–468, pp. 235–238, 2001.

[5] M. Koopmans *et al.*, “Vertical Beam Size Measurement Methods at the BESSY II Storage Ring and their Resolution Limits”, in *Proc. IPAC’19*, Melbourne, Australie, paper WEPGW012.

[6] J. D. Hunter, “Matplotlib: A 2D Graphics Environment”, *Computing In Science & Engineering 2007*, Vol. 9.3, pp. 90–95.

[7] A. Schälicke *et al.*, “Bunch-by-Bunch Feedback and Diagnostics at BESSY II”, in *Proc. IBIC’13*, Oxford, UK, paper TUPC16, pp. 399–402.

[8] F. Falkenstern, *et al.*, “Beam Motion Monitor”, in *BIW2012*, Newport News, VA USA, paper TUPG041, pp. 216–218.

[9] M. Borland, “elegant: A Flexible SDDS-Compliant Code for Accelerator Simulation”, september, 2013.