ISBN: 978-3-95450-208-0 doi:10.18429/JACoW-IPAC2019-MOPGW014

DEVELOPING BEAM OPTICS FOR THE BESSY VSR PROJECT

F. Andreas*[1], P. Goslwaski, F. Armborst[1], M. Abo-Bakr
Helmholtz-Zentrum Berlin, Berlin, Germany
[1] also student at Humboldt-Universität zu Berlin, Berlin, Germany

Abstract

At BESSY II due to the continuously increasing interest in short pulse operation, a major upgrade of the ring will enable simultaneous storage of long and short bunches. This Variable pulse-length Storage Ring (VSR) [1] will be achieved by the installation of additional superconducting high gradient cavities. The cavities will be assembled into one cryomodule in one of the straights of the storage ring. As this module needs more space then initially assumed, one possible solution is to remove two quadrupoles to gain available installation length. The quadrupoles were switched off in simulations and the lattice was optimized with regard to the linear order. The best solution found was transferred to the storage ring, where storage of high current with reasonable injection efficiency and lifetime was possible. The proposed optics has to be further optimized in terms of nonlinear beam dynamics, but has shown that an available installation length can be increased.

MOTIVATION

At BESSY II it is possible to operate the machine in two different modes. Most of the time the storage ring is set to the standard user optics with 15 ps bunch length. During two weeks of the year the lattice is changed to the low alpha optics, which provides buckets with 3 ps bunch length. This can be realized by reducing the momentum compaction factor α_c from $7 \cdot 10^{-4}$ to $4 \cdot 10^{-5}$. The coherent synchrotron radiation instability leads to a limiting bursting threshold current, which scales with α_c. To avoid instabile operation conditions the electron current has to be reduced, leading to a significantly reduced photon flux compared to the standard optics. Under these conditions high flux user are not able to run experiments, which is the reason that the low alpha mode can only be provided for short periods.

Therefore the next major upgrade, BESSY-VSR, aims to provide short and long pulses in one storage ring simultaneously. This variable pulse-length storage ring can be achieved due to the installation of additional cavities. Two 1.5 GHz and two 1.75 GHz cavities will be assembled into one cryomodule in the T2 section of the storage ring (Fig. 1).

As this module needs more space then initially assumed, one possible solution is to remove two most inner Q5T2 quadrupoles, which would result in an effective gain of 66 cm installation length. Before the Q5T2 magnets in the storage ring lattice can be removed, the influence on the beam dynamics has to be investigated in simulations.

* felix.andreas@physik.hu-berlin.de

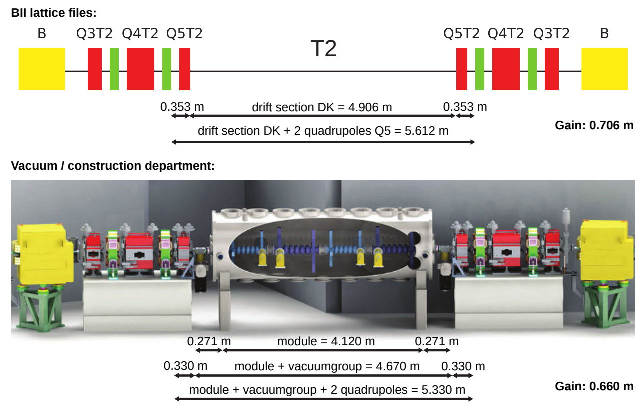

Figure 1: The cryomodule and the magnets of the T2 section (dipole-yellow, quadrupole-red, sextupole-green).

THE BESSY II STORAGE RING LATTICE

The Current Standard Lattice

The current double bend achromat lattice of the BESSY II storage ring, shown in Fig. 2, has alternating high (quadrupole doublet) and low horizontal beta (quadrupole triplet) straights. For the 240 m long storage ring this leads to a 8 fold symmetry with 16 straight sections.

The transfer line for the injection is placed in the D1-straight and the cavity is installed in the T8-straight. The other 14 straight are used for IDs. The doublet sections contain the vertical focusing Q3D and the horizontal focusing Q4D quadrupole families. The triplet straights include the additional vertical focusing Q5T quadrupole family, which is needed to compensate the vertical defocussing of the in comparison to the Q4D quadrupoles stronger Q4T quadrupoles (necessary to achieve a low horizontal beta function).

Requirements for a New Lattice

The aim is to develop an optics where the turn off of the Q5T2 quadrupoles does not effect the other sections and where the overall changes of the beta functions are kept as local as possible. Especially in the femto slicing straight D6, in the EMIL straight T6 and in the injection straight D1 the Twiss parameter should remain unchanged. Also the tunes should stay the same when the Q5T2 is turned off.

Furthermore there are restrictions regarding the BESSY-VSR upgrade. As stated in [2, p. 79] the transverse cavity impedances

$$Z_{\text{th}}^{\perp}(\tau_{\text{d}}^{-1}) = \frac{\tau_{\text{d}}^{-1}}{\beta} \frac{4\pi E/e}{\omega_{\text{rev}} I_{\text{DC}}} \tag{1}$$

scale directly with the value of the beta function and could drive transverse multibunch instabilities. It is assumed that

ISBN: 978-3-95450-208-0 doi:10.18429/JACoW-IPAC2019-MOPGW014

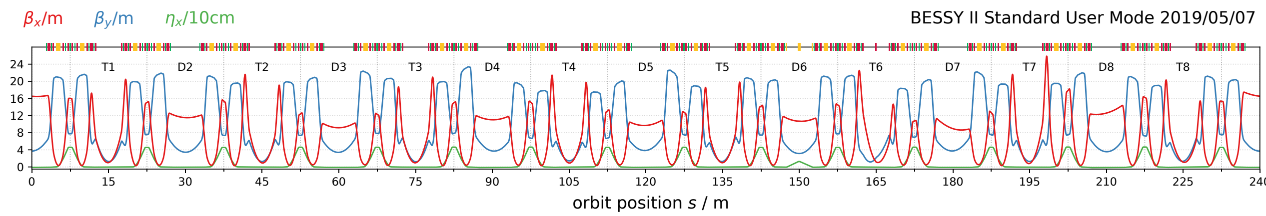

Figure 2: The current standard user optics of the BESSY II storage ring.

with a beta function value below 4 m (shown in Fig. 3 for the design lattice) it is possible to store the required current.

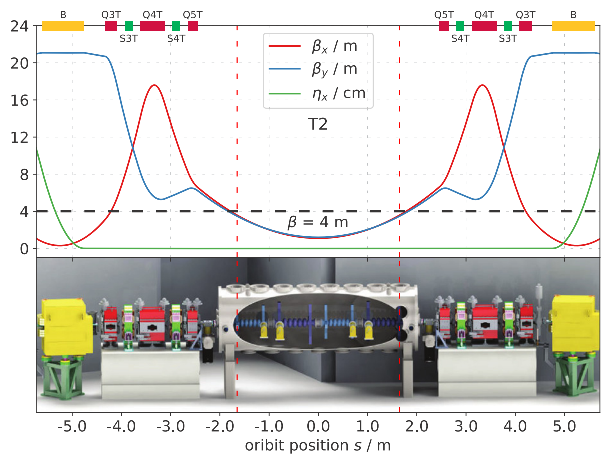

Figure 3: The horizontal and vertical beta functions $\beta_{x,y}$ of the design lattice in the T2 sections (based on [2]).

Using the symmetry of the beta function

$$\beta(s) = \beta^* + \frac{s^2}{\beta^*} \tag{2}$$

in the center of the T2 section, the maximum and average beta function within the 1.50 GHz and the 1.75 GHz cavitiy can be calculated in dependence of the minimum beta function β^* (Fig. 4). As one can see, the goal should be to hold the minimum beta function β^* between 0.6 m and 3.4 m.

SIMULATIONS

Finding a Stable Configuration

Just turning of the Q5T2 quadrupoles in simulations results in an unstable optics. Quadrupole scans can be used to find an initial stable configuration. A quadrupole scan of the current standard optics in dependence of the Q4T2 and Q5T2 magnets is shown in Fig. 5. The scan was verified at the machine: Without chancing any other magnet the Q5T2 could be reduced by 6 % before the beam was lost. Reducing the vertical focusing Q5T2 simultaneously with the horizontal focusing Q4T2 step by step led to a working machine with switched off Q5T2 and an injection efficiency of about 20 %.

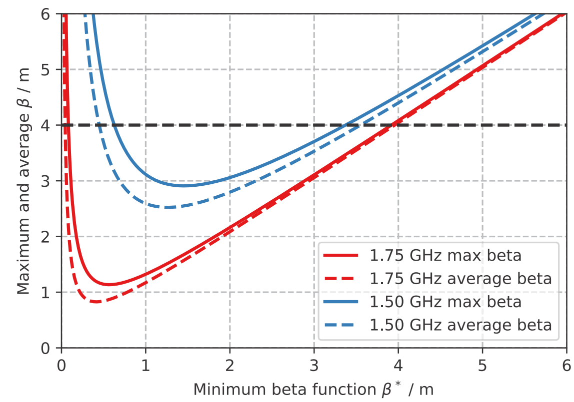

Figure 4: The maximum and average beta function within the cavity in dependence of the minimal beta function β^* in the straight center. (based on [3])

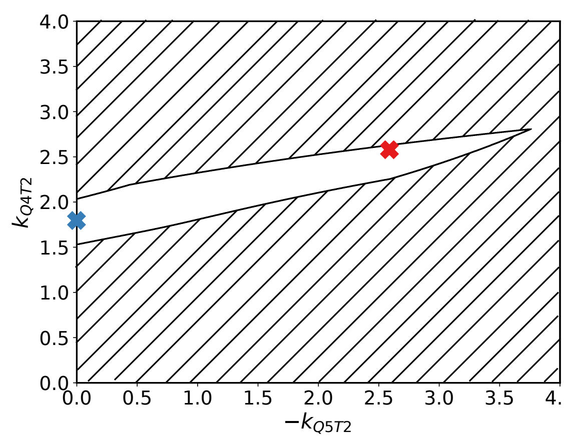

Figure 5: Quadrupole scan of the current standard user optics, where the areas of instablility are crosshatched. The current configuration is marked in red. A stable configuration with a turned off Q5T2 is marked in blue.

Opimization by Minimization of a Scalar Function

To optimize the stable solution found by the quadrupole scan an optimization method was used. The objective function

$$F[\beta] = \frac{1}{L}\int_0^L R\left(\frac{\beta(s)}{\beta_{\mathrm{ref}}(s)}\right)^2 \mathrm{d}s \text{ with } R(x) = \begin{cases} 1, & \text{for } x < 1 \\ x, & \text{else} \end{cases} \tag{3}$$

ISBN: 978-3-95450-208-0 doi:10.18429/JACoW-IPAC2019-MOPGW014

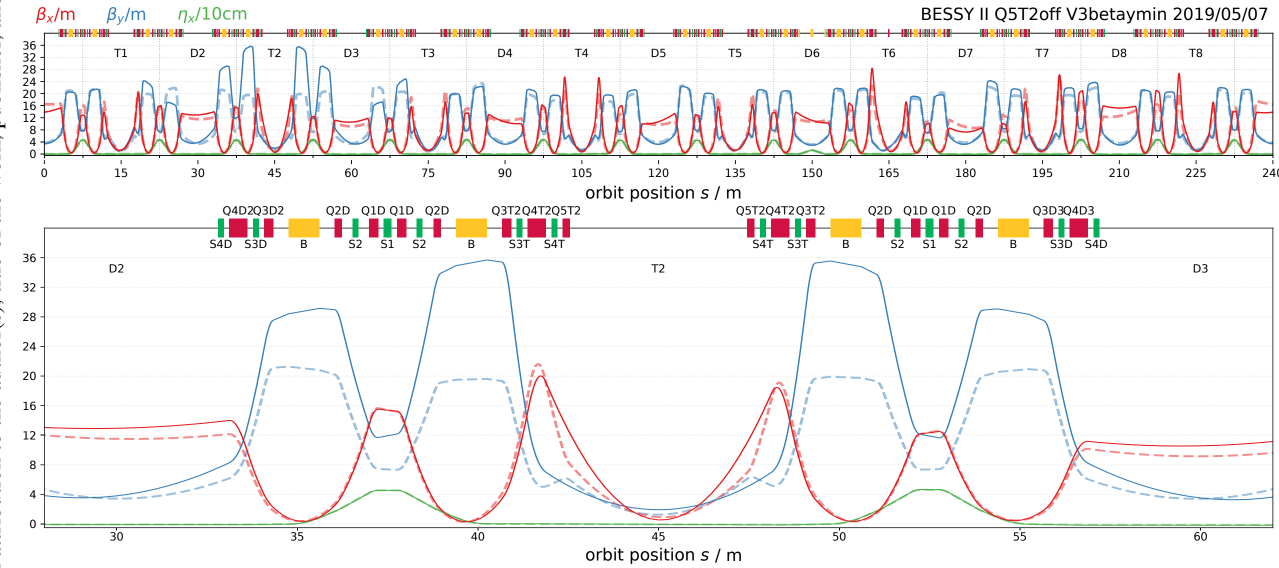

Figure 6: LOCO measurement of the modified standard user optics of the BESSY II storage ring with turned off Q5 magnets. The dashed line corresponds to the unmodified standard user optics.

where β_{ref} is the beta function of the current standard optics, was chosen in that way that it rewards the lattice with the smallest deviation from the current lattice. The relative deviation was preferred over the absolute deviation in the objective function to maintain the small beta function within the straights. Moreover the square of the relative deviation was used to explicitly punish larger relative deviations. The composition of $R(x)$ with the relative change $\frac{\beta(s)}{\beta_{\text{ref}}(s)}$ is used to not take into account negative changes of the beta function.

TESTING THE NEW OPTICS AT THE MACHINE

The optics obtained by the optimization algorithm was transfered to the machine by calculating new power supply values

$$I_{\text{new}} \approx \frac{k_{\text{new}}}{k_{\text{old}}} I_{\text{old}}, \tag{4}$$

from the product of the change of the quadrupole strengths and the old power supply values.

The new optics were measured with the Linear Optics from Closed Orbits method [4] (with the implementation [5] included in the MatLab Middle Layer [6]) and is shown in comparison to the standard user optics in Fig. 6.

As one can see, horizontal beta function of the V4 optics seems very similar to that one of the standard optics. The vertical beta function is up to 16 meters higher within the T2 section and up to 6 meters higher with an asymmetry in center within the D2 and D3 sections, but remains the same inside the other sections. Also in the center of the T2 section the horizontal and vertical beta functions stay below 4 meters with a minimum value β^* of 0.6 and 1.9 meters respectively.

According to [7] the momentum acceptance, i.e. the dynamic aperture, was measured using a phase acceptance

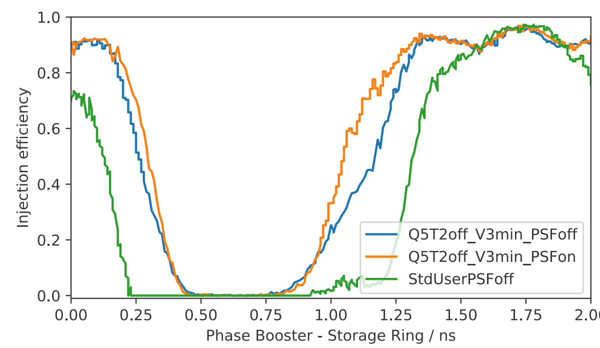

Figure 7: Comparison of the phase acceptance of the standard optics and the modified optics with turned off Q5T2s.

scan (Fig. 7). Thereby the injection efficiency is measured in dependence of the longitudinal phase of the injected bunch, which can be varied by changing the relative phase between the booster synchrotron and the storage ring.

CONCLUSION

The modified optics with switched off Q5T2 quadrupoles were tested at the storage ring with high current with reasonable lifetime and injection efficiency.

The proposed optics has to be further optimized with regard to nonlinear beam dynamics, but has shown that an enlargement of the available installation length by removing Q5T2 is possible. Furthermore it should be tested in simulations if splitting of the quadrupole and sextupole families in the T2, D2 and D3 sections leads to better solutions.

REFERENCES

[1] A. Jankowiak *et al.*, *BESSY VSR – Technical Design Study*.

ISBN: 978-3-95450-208-0 doi:10.18429/JACoW-IPAC2019-MOPGW014

Helmholtz-Zentrum Berlin für Materialien und Energie GmbH, 2015.

[2] M. Ruprecht, *Calculation of Coupled Bunch Effects in the Synchrotron Light Source BESSY VSR*. Helmholtz-Zentrum Berlin (HZB), 2016.

[3] M. Ries, *Private communication*, Helmholtz-Zentrum Berlin (HZB), 2017.

[4] J. Safranek, "Linear Optics From Closed Orbits (LOCO): An Introduction," *Beam Dynamics Newsletter (Print)*, pp. 43–49, 2009.

[5] J. Safranek, G. Portmann, and A. Terebilo, "MatLab-based LOCO," *Proceedings of EPAC 2002,* Paris, France, 2002.

[6] J. Corbett, A. Terebilo, and G. Portmann, "An accelerator control middle layer using matlab," *Proceedings of 2005 Particle Accelerator Conference,* Knoxville, Tennessee, 2005.

[7] P. Kuske and J. Li, "Performance Improvements of the BESSY II Storage Ring by Optimizing the Phase Acceptance," in *Proc. of International Particle Accelerator Conference (IPAC'17)*, Copenhagen, Denmark, May 2017, pp. 2571–2573. DOI: 10.18429/JACoW-IPAC2017-WEPAB006.