Optimization and Tracking Studies for the 1.7 GeV Light Source BESSY II*

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1 INTRODUCTION

BESSY II is a low emittance light source presently under construction in Berlin-Adlershof , Germany [1]. BESSY II will go into user operation in 1998. The general lattice layout was presented in [2]. The main aspects discussed in the present paper are tracking studies including synchrotron oscillation, higher order multipoles in dipoles, quadrupoles and sextupoles and effects of closed orbit errors on the beam and the global correction schemes.

2 THE LINEAR LATTICE FUNCTIONS

The storage ring lattice is based on a 16-fold double bend achromat structure, offering 14 long straight sections for insertion devices and two straight sections reserved for injection elements and rf cavities. The ring will be operated in the energy range from 0.9 GeV to 1.9 GeV, with a nominal value of 1.7 GeV. The main parameters are listed in table 1 and the linear lattice functions are shown in fig.1; for further details see [2].

Table 1 Main ring parameters

Nominal energy	1.7 GeV
Energy range	0.9 - 1.9 GeV
Circumference	240 m
Number of cells	16
Natural emittance ϵ_n	$6{\cdot}10^{-9}$ $mrad$
Natural energy width $\Delta E/E$	$7.0{\cdot}10^{-4}$
Damping times $\tau_x \approx \tau_y/\tau_s$	16.2 / 8.0 ms
Hor. and ver. tune Q_x ; Q_y	17.84 ; 6.82
Natural chromaticity ξ_x ; ξ_y	-50 ; -25
Momentum compaction factor α	$7.5{\cdot}10^{-4}$
Number of dipoles	32
Bending radius	4.361 m
Critical energy	2.5 keV
Max./min. hor. beta function	18/0.31 m
Max./min. ver. beta function	21/1.4 m
Max. dispersion function	0.45 m

As a special feature of the lattice we use alternating high and low horizontal beta functions in the straight sections, whereas the vertical beta functions stay unchanged. In this way superconducting wavelength shifters can be inserted in the low beta sections without influence on the low emittance [3]. The low beta sections use a triplet focussing arrangement yielding a $\beta_x \approx 1m$, in the high beta sections doublet focussing yields $\beta_x \approx 18m$.

The optics as presented in [2] was further optimized to relax the strength of the chromatic sextupoles. This was achieved by a larger vertical beta function at the first chromatic sextupole in the achromat. In this way we get a better decoupling of the beta functions inside the achromat and a more efficient chromaticity correction. The modification of the lattice was obtained by a different quadrupole excitation. All basic parameter and properties of the optics remained unchanged.

3 SUMMARY OF TRACKING CALCULATIONS

Several tracking simulations were performed to estimate the dependence of the dynamic aperture under the influence of higher order magnetic multipoles and corrected closed orbit errors. Many of the calculations were performed and cross checked by different optic codes as BETA,MAD,RACETRACK and TRACY [4].

A discussion of the effects of insertion devices including tracking at a fixed momentum deviation of $\Delta p/p = -3\%$, 0% and +3% was already presented in [2]. The modified

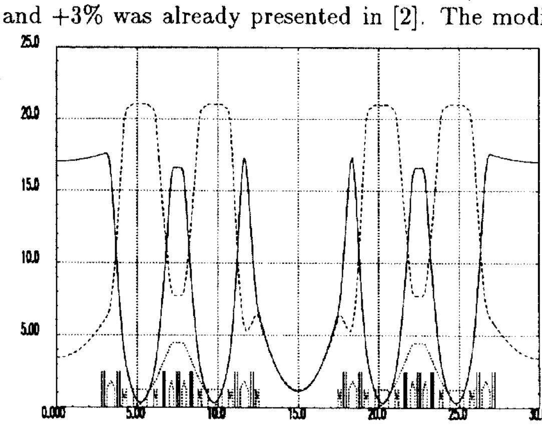

Figure 1: Linear lattice functions of the BESSY II cell.

optics does show the same behavior with respect to the former results. For the optics we expect a momentum acceptance of $-3\% < \Delta p/p < +3\%$. The large momentum acceptance is very helpful for obtaining a life time of more than 10 hours at 100 mA beam current [5]. The rf parameters as used for the tracking are a voltage of 2.4 MV per turn at 500 MHz. For comparison, the bucket limit for

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the momentum acceptance is given by ±5.2%, the longitudinal tune, still in the linear range at the dynamic aperture limit is 0.0081. All results presented include synchrotron oscillation without damping effects.

Typical multipoles as listed in table 2 were included at the entrance and exit points of dipoles, quadrupoles and sextupoles. Systematic multipoles are due to higher order symmetries of the magnets, whereas the random multipoles are due to the expected fabrication tolerances of the magnets deteriorating the symmetries of the multipoles. For the calculation with MAD the insertions were modeled by a linear dipole sequence, adding at the start and end of each period the same type of nonlinear error as in case of the dipoles (see table 2). However, this approach does not describe the tune shift with vertical amplitude correctly. Nonlinear effects of the insertion were studied in [2].

Before starting the tracking simulations, closed orbit errors, as discussed in the next section, were generated and corrected by dipole correctors localized inside of sextupoles. After correcting the orbit to typically less than 0.1 mm as a rms displacement from the idealized orbit, the deviations in the transversal tunes from its nominal values were neglectibly small.

Table 2: Integrated strength of multipole coefficients used in tracking calculations $L \cdot K_n = L \cdot (\partial B_y / \partial x^n)/B\rho$

Multipole order n (n=3⇒sextupole)	LK_3	LK_4	LK_5	LK_6	LK_9
Ring magnets:					
Dipole	0.16	-	310	-	-
Quadrupole	0.038	3.3	27.4	1900	-
Sextupole	-	-	-	-	$2 \cdot 10^{11}$
ID/period	0.0016	-	0.31	-	-

An example of the resulting aperture is given in fig.2. The stable range of the dynamic aperture for the bare lattice is of the order of the good field limit of the magnets, which is expected at ± 3 cm horizontally and outside of limiting chamber walls at ± 2 cm vertically. Further studies are done for selected multipoles; the contribution of the $L \cdot K_6$ term inside the quadrupole magnets was the most sensitive. With the additional activation of 14 insertion devices the dynamic aperture reduces to ± 2 cm horizontally, see fig.2.

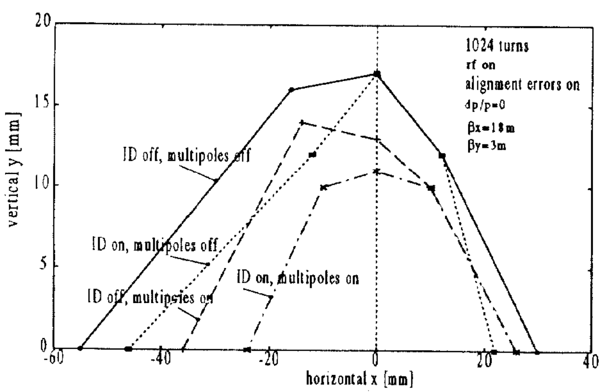

Figure 2: Display of some of the MAD-tracking results .

Based on these tracking studies together with expected life time limitations of the beam due to Touschek effect and residual gas scattering [5] the dimensions of the vacuum chamber were fixed to ± 3.5 cm horizontally and ± 2 cm vertically. Theses numbers, transferred to the observation point in fig.2, yield ± 3.5 cm horizontally and ± 0.8 cm vertically.

4 CLOSED ORBIT CORRECTION

Schemes for a global closed orbit correction system were studied [6] and results are summarized here. This system will correct the position of the closed orbit with respect to slow drifts on a time scale of some minutes or more. For the absolute calibration of the closed orbit with respect to the magnetic elements an rms-value of 0.13 mm is expected, the relative positioning stability will be by at least a factor of ten better. Independent of these correctors and monitors a fast feed back system for beam positioning inside the insertions is planned.

Dipole correctors for the global correction scheme will be excited by pole face windings inside of sextupoles, because the dense packed BESSY II lattice does not allow for separated correctors. We discarded the possibility of including them into quadrupoles, to avoid hysteresis effects on dispersion and working point.

The signal of the horizontal and vertical beam position will be detected by standard button monitors. For 1/16 of the ring circumference there are 7 button monitors installed per section. Inside each sextupole we will kick the beam by the corrector only in one plane, however, poleface windings for both planes are planned. The designed maximum kick strength will be 1.5 $mrad$. The location of the correctors and the monitors are shown in Fig.3. We did compare schemes including 3 to 5 correctors in the horizontal plane and 2 to 4 correctors in the vertical plane, results are shown in Fig.4. We quote here the results from the 3 horizontal and 2 vertical corrector scheme.

The calculation of the correction scheme is based on typical field and alignment errors for the magnetic elements as given in [7]. The results obtained for the corrected orbit and strength of correctors are dependent on the method. We present here results calculated with the MICADO algorithm included in MAD. Based on 100 different error sets, several statistical results can be derived. A comparison of some of these number are given in table 3; in the brackets are those numbers which we found for our optics. Espe-

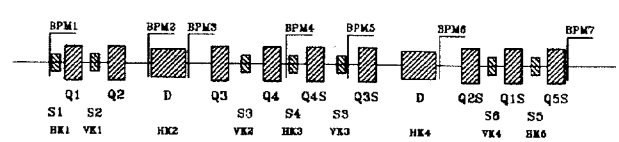

Figure 3: Scheme of monitor and corrector location.

cially, a corrected closed orbit deviation of an *rms*-value of 0.06 mm with respect to the theoretical ideal orbit is expected.

From these results we can estimate the vertical beam size. The coupling of the transversal phase space ϵ_y/ϵ_x was calculated using a statistical estimation by [8], which takes into account two sources of skew quadrupoles: rotated quadrupoles and a vertical beam positioning error inside of sextupoles. This calculation gives an estimation of 0.5 % coupling, with the largest contribution originating from the sextupoles. Different to the present, not fully adjusted working point, this estimate is valid for a separation $\Delta Q = 0.1$ of the noninteger parts of the working points.

Small values of vertical dispersion inside the dipoles give further contributions to the vertical emittance. We expect an additional value of $\epsilon_y = 2\cdot 10^{-11}\ radm$. The wavelength shifter will not contribute more than the other dipoles to this value.

Vertical dispersion at the source point of the photon beam and the final energy width of the electron beam will give a contribution to the beam width of $\sigma_y = 3\mu m$. Summarizing these effects we expect an *rms*-value for the beam dimension of 12 μm at the insertion device location.

Table 3: Selected *rms* error value relations
x=horizontal plane,y=vertical plane

Before correction			
closed orbit beating vers. quadrupole displacement:			
$\langle x\rangle[m]$	=	$110\langle\Delta x\rangle[m]$	$(= 0.013m)$
closed orbit beating vers. quadrupole rotation:			
$\langle x\rangle[m]$	=	$20\langle\theta_y\rangle[mrad]$	$(= 0.005m)$
closed orbit beating vers. quadrupole displacement:			
$\langle y\rangle[m]$	=	$107\langle\Delta y\rangle[m]$	$(= 0.013m)$
closed orbit beating vers. quadrupole rotation:			
$\langle y\rangle[m]$	=	$15\langle\theta_x\rangle[mrad]$	$(= 0.004m)$
After correction			
vert. emmitance vers. vert. dispersion:			
$\langle\epsilon_y\rangle[rad\,m]$	=	$1.9\cdot 10^{-9}\langle D_y\rangle[m]$	$(= 2\cdot 10^{-9})$
vert. dispersion vers. quadrupole rotation:			
$\langle D_y\rangle[m]$	=	$0.015\langle\theta_x\rangle[mrad]$	$(= 0.0015m)$
vert. dispersion vers. dipole rotation:			
$\langle D_y\rangle[m]$	=	$0.005\langle\theta_{long}\rangle[mrad]$	$(= 0.001m)$
vert. dispersion vers. quadrupole displacement:			
$\langle D_y\rangle[m]$	=	$33\langle\Delta z\rangle[m]$	$(= 0.004m)$
vert. dispersion vers. sextupole displacement:			
$\langle D_y\rangle[m]$	=	$66\langle\Delta z\rangle[m]$	$(= 0.008m)$
coupling vers. quadrupole rotaion:			
$\langle\kappa\rangle$	=	$12\langle\theta_x\rangle[rad]$	$(= 0.0015)$
coupling vers. sextupole displacement:			
$\langle\kappa\rangle$	=	$36\langle\Delta y\rangle[m]$	$(= 0.0048)$

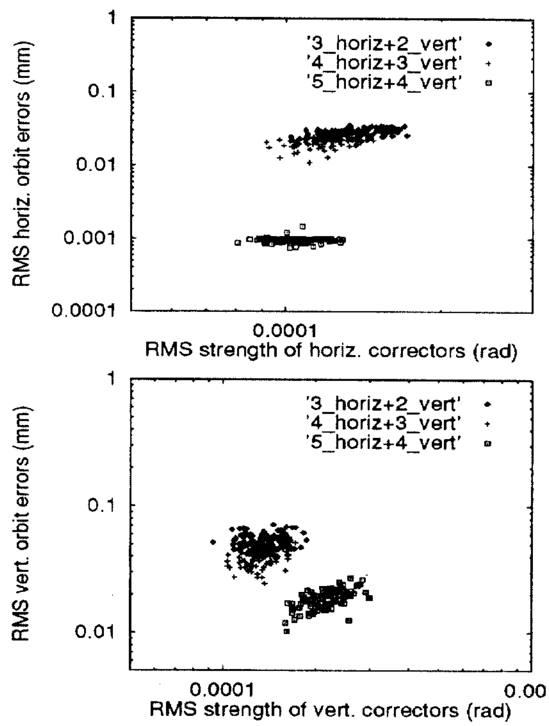

Figure 4: Resulting closed orbit error as a function of different numbers of correctors.

5 ACKNOWLEDGEMENT

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