BESSY II
A Synchrotron Light Source of the Third Generation

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Introduction

BESSY II is proposed as a third generation, low emittance storage ring for the production of high brilliance photon beams. Eight straight sections are planned for insertion devices. In addition eight bending magnets will be available for dipole radiation. Special design goals are the low horizontal beam emittance of $8 \cdot 10^{-9}$ π·m·rad and a very short bunch length of 20 ps to 50 ps due to the small momentum compaction factor of about $1.2 \cdot 10^{-3}$.

The storage ring presents a tenfold symmetry with 5 m long dispersion free straight sections. The nominal energy is 1.5 GeV with a maximum beam current of at least 100 mA. The beam half life time in the ring should be more than 5 hours. The main design parameters are given in Table 1. The injection into the BESSY II storage ring will be done at 850 MeV via a transferline from the existing, already upgraded BESSY I injector. The beam will be injected horizontally from the inside of the ring. A three kicker bump is used to displace the orbit of the stored beam locally at the injection point in one of the dispersion free orbit sections.

Linear lattice

The present reference design has a tenfold symmetry consisting of a triple bend achromat lattice (TBA) with 182.4 m circumference. The straight sections are 5.2 m long. The straights will supply dispersion free space mainly for wigglers and undulators, but also for injection elements and RF cavities. This kind of lattice is very well proved in the existing BESSY I storage ring /1/. The layout of one superperiod is shown in fig.1. The summary of the major storage ring parameters is given in tab.2. The dipole magnets are of the H-type and are gradient free. The magnet gap is 0.05 m, with a maximal magnetic induction of 1.7 T at 1.95 GeV. The lengths of the quadrupoles are 0.4 m with a maximum field gradient of 15 T/m at 1.5 GeV.

The proposed TBA structure is sufficiently flexible to satisfy the beam dynamical requirements. The size of the beta function in the straights and the tune of the ring can be controlled to some extent independently.

Fig.2 shows the lattice functions (β_x, β_y, D_x) in one superperiod of the storage ring. The example shows a lattice with a high value for the radial beta function of about 10 m in the straights and a vertical beta function of about 2.5 m. With these values the radial phase advance in the unit cell is more or less fixed to 540 degrees with overall tunes of 12.75 horizontal and 7.05 vertical.

The natural emittance is defined by the beta and dispersion functions inside the dipoles. The dispersion function H

$$H = \gamma D_x^2 + 2\,\alpha\, D_x D'_x + \beta D'^2_x$$

is conserved between the dipoles. If we want to minimize the natural emittance we have to consider that the exit value of H in the first dipole is the starting value of H in the second dipole. The derivative of the dispersion D'_x must be adjusted to $\pm 1/2\, \Theta_B$ at the boundaries of the inner dipol to get a symmetric solution of the dispersion function with respect to the lattice, where Θ_B is the deflection angle inside the dipole.

A special set of minimized values of the natural emittance is achieved if we fix the value of the dispersion D_x in the center of the second dipole equal to zero[2]. Now we choose the minimum of the beta function in the inner dipole just four times its value in the outer dipole. In this case the outer dipole is centered close to the minimum of the beta function. For this relation Fig. 3 shows a plot of the emittance as a function of the minimum of the beta function b_1 in the outer dipole. The beta function is normalized to the bending radius. This solution is not the smallest possible value but it is very close to the absolute minimum which can be achieved. The parameter k which characterizes the TBA lattice with respect to the minimum natural emittance ε_N is

$$\varepsilon_N = k\, \gamma^2\, \Theta_B^3$$

and $k = 3.4 \cdot 10^{-14}$ π·m·rad^{-2}. The weak focussing in the dipoles is neglected in this consideration. The present lattice is up to now not optimized with respect to this concept.

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Knowing the minima of the beta function in the dipoles and choosing a value of 10 m for the straight sections we can calculate the chromatic effects generated at these points. This is added to the figure. However, there are further contributions to the chromaticity due to the setting of the quadrupoles. This has still to be optimized, with the fixed shape of the beta function inside the insertions.

Single particle effects due to non-linearities are characterized by the dynamic aperture, which is mainly influenced by the chromatic effects. For the uncorrected chromaticity we found -24.0 horizontal and -18.8 vertical. Two families of sextupoles are required to correct the chromaticities. The dynamic aperture without the presence of magnetic imperfections is shown in Fig. 4 in coordinates normalized to the square root of the betatron amplitudes.

Fig. 5 shows the momentum dependent tune shift. The momentum acceptance of the lattice of more than +/- 3% in dp/p gives a sufficient Touschek lifetime at 100 mA stored current.

Wigglers and undulators

There are several interactions between the beam and the insertions, as tune shift, modulation of the beta function around the circumference and reduction of the dynamical aperture, which should not severely disturb the beam. Experiences at several laboratories show that these effects will affect the beam and a significant effort must be made to keep them to tolerable levels.

RF Installation

There are two RF cavities to be installed with 1.1 MV per turn. They will run at 500 MHz which corresponds to the 304th harmonic of the revolution frequency. The peak voltage has to supply a reasonable longitudinal acceptance to capture the bunches from the injector and care for scattered particles. The radiation losses at 1.5 GeV will be only ten percent of the peak voltage times unit charge. With two additional cavities the beam energy can be extended to 1.95 GeV without problems. The limit is than given by the peak field in the dipole magnets. Further RF-parameters are listed in tab. 3.

There is the option to add a 2nd or 3rd harmonic to the 500 MHz RF system at a rather modest peak voltage of 3 kV. This could stabilize coupled bunch oscillation by Landau damping. Additionally one could independently manipulate the bunch length due to the requirements of the users without changing the lattice parameters or the RF setting of the first harmonic.

Particle losses and collective effects

There are two types of particle losses, single particle and collective effects studied for BESSY II /3/. Both mechanisms depend on the particle energy and the lattice setting and one on the current and its density.

To keep the mean lifetime of the beam longer than 6 hours, the electron losses via residual gas scattering have to be kept below a special value, which requires that the pressure in the ring be less than 10^{-9} mbar.

For the multi-bunch mode consisting of 250 bunches with a 100 mA mean current the influence of collective effects are quite low, also in the case of 1% coupling between the transverse emittances. More severe effects become dominant in the single bunch mode with 7.5 mA mean current. In this case a doubling of the bunch length (twice the rms value) from 50 ps to 100 ps should be considered.

Practically no difference appears in the transverse emittance growth due to intrabeam scattering between the single bunch and multi-bunch mode above 1 GeV. Whereas below this value the intra beam scattering becomes worse for the single bunch mode. In any case, the expected emittance growth will be less than a factor of two.

The calculated lifetime of the beam due to the Touschek effect will be about 10 hours. The residual gas pressure has to be adjusted to give the same lifetime, which requires a pressure of $< 10^{-9}$ mbar. Both will result in an overall lifetime of 5-7 hours. These calculations depend rather strongly on the aperture limitations in the undulators.

The multi-bunch mode of more than 100 mA mean current could excite coupled bunch transverse and longitudinal oscillations of the dipole mode type. This might require some special damping. A feedback system or a higher-mode damping of the cavity could handle this instability.

We acknowledge the fruitful discussions with A. Jackson, A. Wrulich, and M. Zisman.

References

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[2] G. Wüstefeld, BESSY TB 108/87, Minimierung der natürlichen Emittanz im TBA Lattice (March 1987)

[3] M. S. Zisman, Influence of Collective Effects on the Performance of BESSY II, BESSY (August 1986)

Tab.1: Design Parameters of BESSY II

nominal beam energy	1.5 GeV
beam current	100 mA
number of bunches	1..304
beam horizontal emittance	$8\cdot10^{-9}$ $\pi\cdot$m$\cdot$rad
beam lifetime	> 5 h
number of straight sections	10
length of straight sections	< 5 m

Tab.3: RF Parameters

rf-frequency	499.654 MHz
harmonic number	304
peak voltage per turn	1.1 MV
shunt-impedance of a single cavity	3.2 MOhm
number of cavities	2
beam current	100 mA
rf-power	155 kW

Tab.2: Major Storage Ring Parameters

circumference	182.4 m
tunes horizontal/vertical	12.75 / 7.05
momentum compaction factor	$1.3\cdot10^{-3}$
energy loss per turn	117 keV
natural energy spread	$6.6\cdot10^{-4}$
chromaticities horizontal/vertical	-24.0/-18.8
maximal horiz./vert. beta functions	23.3 m /5.2 m
mean radius	28.9 m
horizontal damping time	15.7 ms
vertical damping time	15.5 ms
longitudinal damping time	7.7 ms

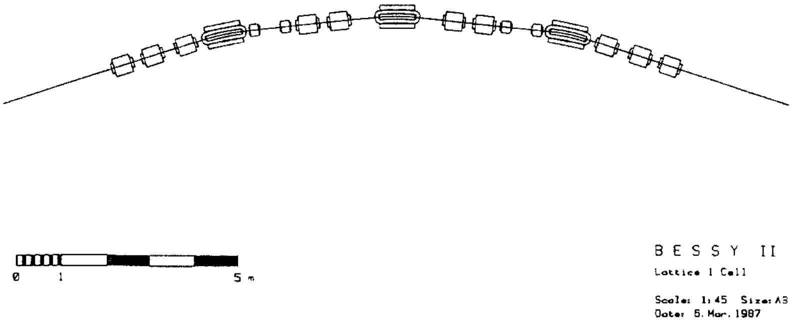

Fig. 1: Layout of one unit cell

BESSY

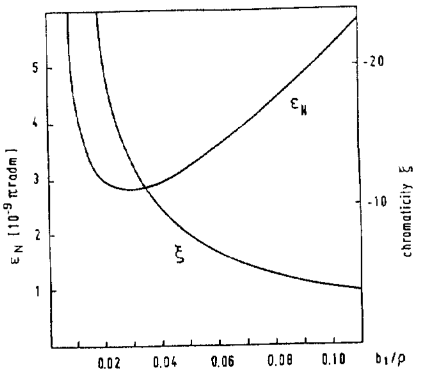

Fig. 3: Optimized natural emittance vs. the minimum of the horizontal beta function

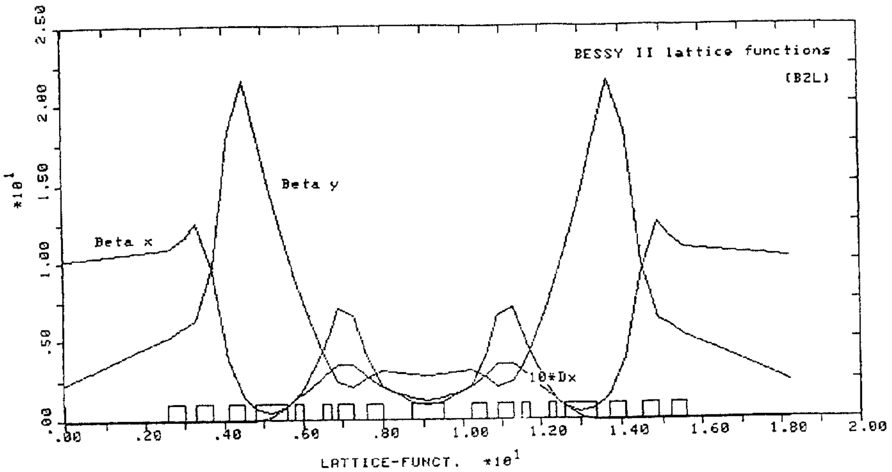

Fig. 2: Twiss parameters of one superperiod

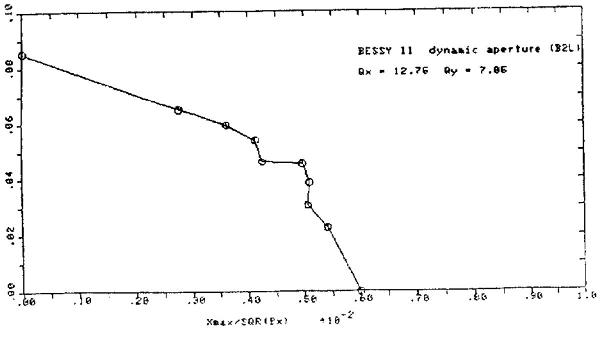

Fig. 4: Normalized vertical vs. horizontal amplitude limits

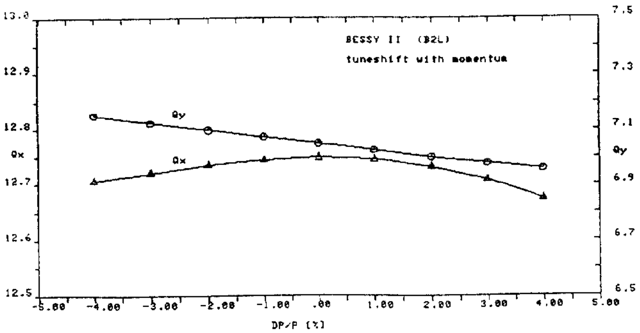

Fig. 5: Momentum-dependent tune shift vs. dp/p