Lattice Design for the 1.7-GeV Light Source BESSY II *

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1. Introduction

BESSY II is a third generation synchrotron radiation light source presently under construction at Berlin-Adlershof /1/. BESSY II will go into operation at the end of 1997. In this paper, the main lattice features of the low emittance storage ring are presented. Special aspects of the design are a compact and flexible double bend achromat (DBA) lattice, which offers 16 straight sections at a circumference of 240 m. About 3 superconducting wave length shifters (WLS) are foreseen for operation.

2. General Design Goals

The user requirements for the BESSY II storage ring are discussed in the design study /2/. The main design goals are a low natural emittance of the order of $5 \cdot 10^{-9}$ rad m and a large number of long, straight sections for insertion devices (IDs). Recently, there was a further demand for about 3 superconducting WLSs, compatible with the low emittance operation of the ring.

The WLSs will be used for micro mechanics application and for radiation-metrology. A detailed study of the effects of these WLSs on the beam emittance and beam stability was done in /3/. It was found that for the operation of the WLSs at low emittance conditions, a horizontal beta function of ≈0.80 m and a vanishing dispersion at the WLS location are required.

The early plan was to build the BESSY II ring close to the present BESSY I site at Berlin-Wilmersdorf. Because of space limitations there, a 10-fold triple bend achromat (TBA) was the favoured solution /4/. After the reunification of Germany, a new site for BESSY II was chosen on the former site of the East German "Akademie der Wissenschaften" at Berlin-Adlershof which offers a larger area. With a circumference enlarged by 25% a compact double bend solution is possible, which offers 16 straight sections, 14 could be used for IDs. For further information on the general scheme of BESSY II see /1/.

3. The Storage Ring Lattice

Several achromats were studied for the storage ring lattice, such as FODO types, triple bends (TBA) /4/ and double bends (DBA). We found that the DBA was superior to other solutions with respect to the compactness of the achromat and the number of magnets required.

Table 1: General 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	$6.1 \cdot 10^{-9}$ *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	-45 ; -24
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	17.2/0.384 *m*
max./min. ver. beta function	20.5/2.44 *m*
max. dispersion function	0.415 *m*

For the DBA type we obtained good results for the emittance and the dynamic aperture. Since the BESSY II ring is designed for an effective use of IDs, the number of 14 usable straight sections further supports the DBA solution. The main parameters of the DBA are summerized in the Tab. 1, and Fig. 1 shows the lattice functions of half a unit cell.

In order to tune the DBA lattice to the theoretical minimum emittance, a long achromat with a minimum of the horizontal beta function is necessary. We did apply a different approach by choosing a very compact achromat to obtain space for more unit cells around the planed circumference. We are away from the minimum emittance by a factor of 3 but we obtain the required emittance through the larger number of unit cells ($\epsilon_n \propto 1/(\text{number of cells})^3$).

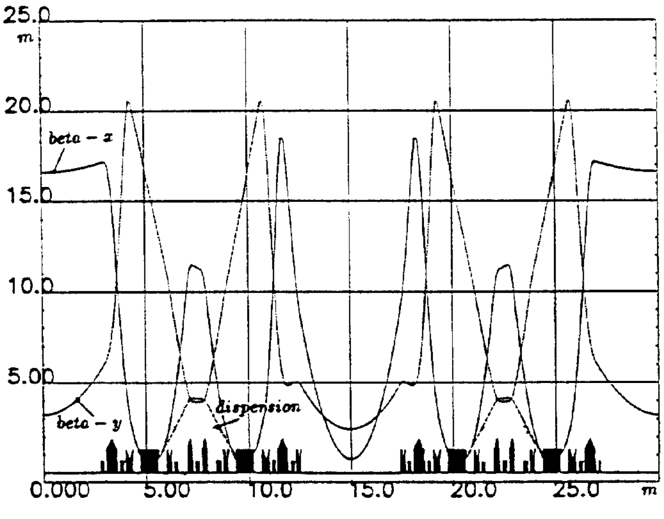

Fig.1 Lattice functions of the BESSY II DBA cell.

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Table 2: Parameter List For Typical Insertion Devices

ID name, ring dipoles	WLS1	WLS2	U11	U33	U25	dipole	ID sum	dipole sum
number of IDs, dipoles	1	2	4	3	4	32	14	32
length ID, dipoles [m]	0.60	0.70	4.00	3.30	4.16	0.856	44.5	27.4
field strength B_0 [T]	7.5	5.6	1.1	0.58	0.46	1.3	-	-
period length [m]	-	-	0.10	0.03	0.052	-	-	-
lin. tune shift ΔQ_y $^{a)}$	0.044	0.026	0.018	0.0038	0.0031	-	0.190	-
non.lin. tune shift ΔQ_y $^{b)}$	-	-	0.0035	0.0083	0.0022	-	0.047	-
radiated power [kW] at 1.7 GeV and 100 mA	2.30	1.38	0.92	0.20	0.16	0.53	10.0	17.0

$^{a)}$= calculated at $\beta_y = 2.8m$; $^{b)}$= octupole-like tune shift; calculated at $\beta_y = 2.8m$ and $y = 1cm$;

To obtain horizontally parallel synchrotron radiation out of the undulators and for injection, a large beta function in the straight section is optimal, whereas for the WLSs operation a low beta function is required. To satisfy these contradicting demands we use a structure where the vertical beta function is ≈2.8 m in all straight sections, but the horizontal beta function is alternating between 16.6 m an 0.75 m from one straight section to the next.

In this way we arrive at an 8-fold periodicity with 16 straight sections. The focussing in the high beta straights is done by using a quadrupole doublet and in the low beta straights by using a triplet. The length of the low beta straight is shorter than the length of the high beta straight by the length required for the third quadrupole family. Thus there are two types of straight sections, leaving free space for IDs up to 4.71 m and 3.89 m in length. With the third quadrupole family switched off, the lattice can be tuned to a 16-fold symmetry.

There are 6 sextupole families required to correct higher order effects in the optics . The beta and dispersion functions inside the achromat show nearly a 16-fold symmetry; therefore two chromatic sextupole families are sufficient to adjust the chromaticity. For the harmonic correction the two groups of straight sections require two different families of sextupoles. The harmonic sextupoles are only differently powered but at equal locations in the straight sections to preserve the option for a 16-fold symmetry.

The 16-fold symmetric lattice solution shows excellent properties with respect to linear and non-linear beam dynamics but is not further discussed here.

4. Nonlinear Lattice Effects

While the work on the linear lattice was done using the code LATTICE /5/, the nonlinear behaviour of the optics was mainly studied using the codes BETA /6/ and RACETRACK /7/. For all tracking calculations, the setting of the chromatic sextupoles was adjusted to obtain a non-normalized chromaticity of +1 in both planes, required to suppress head-tail effects.

The higher order chromatic tune shift is reduced by the setting of the harmonic sextupoles, because the DBA does produce some small second order dispersion (≈3m) outside of the achromatic bends.

Harmonic sextupoles are required to reduce the amplitude dependent tune shift by a factor of ≈3 to a value of ≈0.1 for particles at the limit of the dynamic aperture.

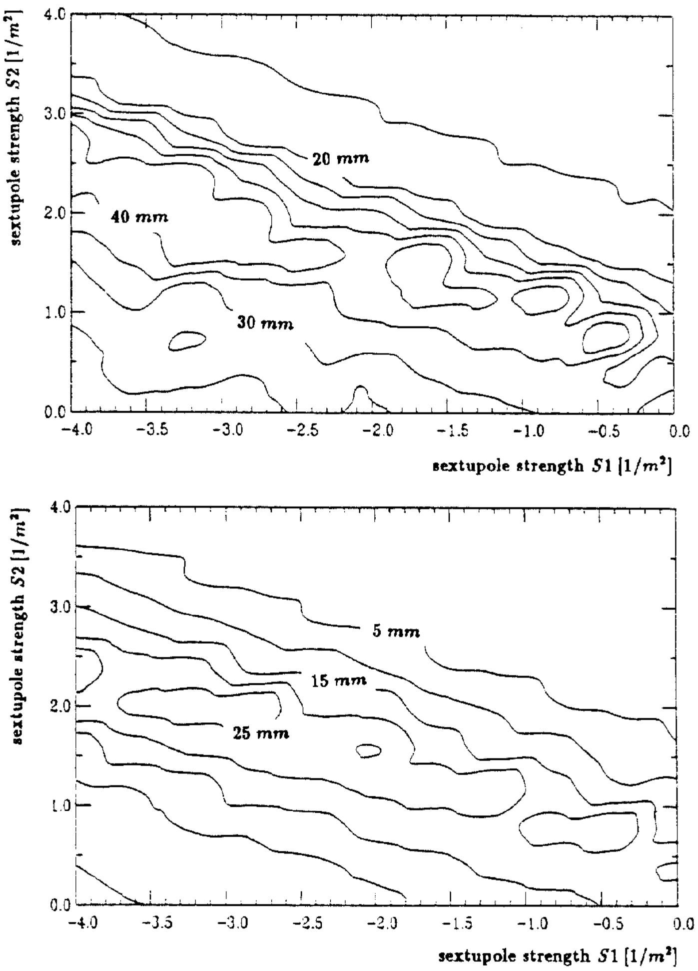

Fig.2 A contour-plot of the dynamic aperture as a function of the strength of the two harmonic sextupoles in the low beta section. The aperture is measured at the high beta section with $\beta_x = 16.6m$ (upper picture)and $\beta_y = 3.2m$ (lower picture), the tracking results are given for 400 stable turns.

The optimum sextupole strength is found by comparing the dynamic apertures at different sextupole settings. In Fig. 2 the dependence of the dynamic aperture on the strength of the two harmonic sextupoles in the low beta section is shown. Both transverse planes are optimized simultaneously, and the result has a broad maximum. In this calculation the second group of harmonic sextupoles in the high beta section is kept at a fixed, optimized value. The results are observed at the the high beta section.

5. Effects on the Beam Due to Insertion Devices

In the final version, 14 IDs will be installed in the BESSY II ring. These IDs will cover 44.5m or 18 % of the ring circumference. Beam dynamical effects of the IDs are simulated with 3-dimensional, highly periodic magnetic fields derived from the scalar potential of the type:

$$V = -(B_0/k_y)\,\cos k_x x\,\sinh k_y y\,\cos ks\;,\quad k^2 = k_y^2 - k_x^2$$

and $k_y = 5k_x$ to simulate a small transverse gradient. The period length λ of the ID in longitudinal direction s is related to the wave number k by the expression $\lambda = 2\pi/k$.

This field expansion is probably good for IDs with many periods and negligible entrance field effects. For the tracking simulation of these types of IDs a fast and precise tracking routine was developed /8/. The WLS with only one main pole and a strong linear term was studied by taylor-ing a tracking routine to the explicit magnetic field shape /3/. However, for our low beta section a simplified approach based on the above field expansion was possible as well.

A parameter listing of typical IDs used in the tracking simulation is given in Tab. 2. Furthermore, a linear and nonlinear tune shift can be estimated due to quadrupole- and octupole- like fields acting mainly in the vertical plane.

In the tracking simulation, the linear effects of the IDs are corrected by simply readjusting the global tune with the doublets in the high beta sections. For the WLSs we did apply in addition a local quadrupole (triplet) correction to cancel the beta beat. Since the beta beat is not always explicitly canceled in the present method, there remains a beating of up to ≈30%. We still could apply a full correction of the beta beat introduced by an ID with the adjacent doublet.

The effects of the IDs on the transverse beam dynamics was simulated by the tracking codes BETA and RACETRACK. Results of the tracking simulation with and without 14 IDs are presented in Fig. 3. All tracking calculations are done with small position and strength errors of the magnetic elements. These errors generate closed orbit oscillations with an rms value up to 5mm. The presented results are not corrected with respect to these errors in order to simulate a symmetry break of the optics. Further tracking studies, based on realistic errors and their correction and also including some skew quadrupoles at the IDs location have been done but are not presented here.

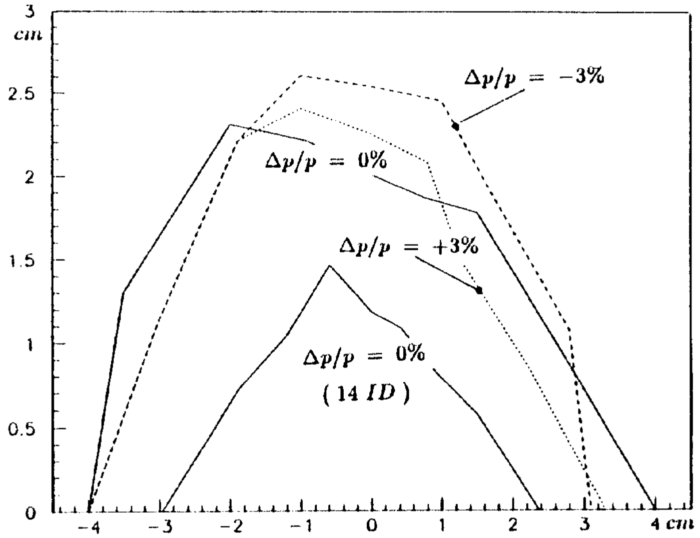

Fig.3 Dynamic aperture results for 1000 stable turns with small errors activated to break the ring symmetry. The calculation for the bare lattice was done at a momentum deviation of -3%, 0% and +3%. The beta function at the observation point are $\beta_x = 16.6m$ and $\beta_y = 3.2m$. For the nominal momentum a tracking example is shown for a filling of the ring with 14 IDs leaving the other parameters are unchanged.

6. Acknowlegments

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