LAYOUT OF THE BESSY II LATTICE

B. Kuske, G. Isoyama*, H. Lehr, G. Wüstefeld
Berliner Elektronenspeicherring-Gesellschaft für Synchrotronstrahlung m.b.H. (BESSY), Lentzeallee 100, D. 1000 Berlin 33
* on leave from Institute for Solid State Physics, University of Tokyo, Japan

1. Introduction

Studies of different types of lattices and methods of lattice development have been performed at BESSY [1, 2, 3, 4, 5], before the final lattice for BESSY II, a third generation synchrotron light source for the use of wigglers und undulators, was selected in 1989 [6]. The main points of concern during the decision process have been i) in how far the particle losses due to the limited momentum acceptance and dynamic aperture can be minimized and ii) how well the disturbing effects of the insertion devices can be compensated. We ended with a tenfold TBA-structure with quadrupole triplets in the straight section, a quadrupole doublet in the achromatic section and five families of sextupoles.

2. Description of the main lattice features

The main parameters of the lattice are listed in table 1. For a further description of the lattice see [6].

Table 1: Main Lattice Parameters

Energy [GeV]	1.7 (0.9-1.9)
Circumference [m]	194.39
Number of superperiods	10
Natural emittance [nmrad]	6.2
Tunes Q_x, Q_z	14.16/6.18
Chromaticities ξ_x, ξ_z	-39/-13
Bending radius of dipoles [m]	4.2
Harmonic number	324
Physical aperture A_x, A_z [mm]	±20/±10
Rf [Mhz]	499.666
Momentum compaction factor	$0.155 \cdot 10^{-2}$
Place for insertions	8
Length of straight section [m]	5.8
Nat. energy spread	$0.71 \cdot 10^{-4}$
Damping times τ_x, τ_z, τ_ε [ms]	12.7/12.7/6.2
Revolution time [ns]	648

Out of the different possible focussing structures next to the insertion devices (ID), a D-F-D triplet (D = horizontally defocussing) provided the best performance compensating the distortions of the beta functions due to the IDs and restoring the tune of the machine. In addition, the beta functions can be varied in a wide range at the place of the IDs, and a low vertical tune and small vertical chromaticity is achieved. The principally high contribution of this triplet structure to the horizontal chromaticity has been reduced by requiring a moderate horizontal beta function in the straight section.

A detailed study of the dynamic aperture showed, that more than two families of sextupoles are needed to control the tune shift of particles with large amplitudes and with different momenta. Three families of sextupoles in the dispersive region of the lattice allow to minimize the tune shift and beta beat for particles with momentum deviation, and with two additional sextupoles in the straight section the amplitude dependent tune shift can be controlled.

With these magnets a tenfold symmetry could be realized on the circumference of only C = 194 m. The magnet structure and beta functions of one super period are shown in Fig. 1.

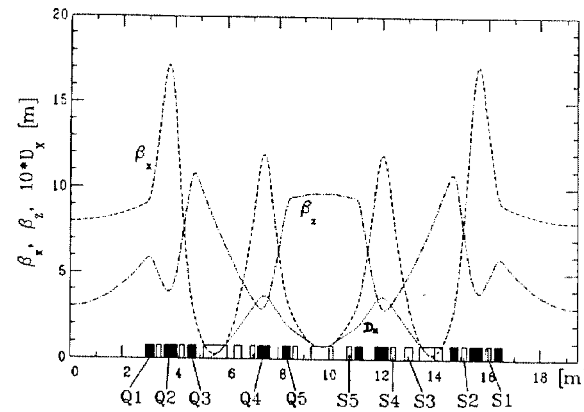

Fig. 1: The magnet structure and the optical functions of the BESSY II lattice

In the range of Q_x = 14.0-14.5 and Q_z = 6.0-6.5, no structure resonances exist up to forth order for the tenfold symmetry structure. In the vicinity of the chosen tune Q_x = 14.16, Q_z = 6.18, only non-structure difference resonances occur, which will not cause direct particle losses.

3. How to deal with the insertion devices

For the compensation of the linear effects of an ID, only the three quadrupoles to the right and the left of the ID shall be used, in order to maintain the achromaticity of the lattice.

Table 2: Main Parameters of typical IDs

ID	K	periods no.	periods L[m]	max. beat hor. %	max. beat ver. %	max ΔQ hor.	max ΔQ ver.
W2	9.7	40	0.10	1	< 10	.002	.017
U1	2.2	40	0.10	-	~2	-	.001
U3	1.6	110	0.03	-	~3	-	.005
WLS	280.2	1	0.60	5	40	.006	.050

Except for a 5 T wavelength shifter (WLS), all planned IDs for BESSY II (see table 2), used as single insertions, cause beta beats of less than 10%. This corresponds to the beat existing in real machines due to errors [7] and needs not be compensated. The need for beat correction (which is difficult and time consuming to measure) might arise by the parallel use of many IDs, because their relatively small single beta beats might add up to unacceptably large values. The tune shift of each ID except for the WLS is $\Delta Q_x < 0.002$ and $\Delta Q_z < 0.02$, and the need for tune correction is not evident according to tracking calculations.

Global, local and combined global/local compensation schemes are feasible. Global correction schemes, i.e. excitation of whole quadrupole families, have the disadvantage to create crosstalk between the IDs, since the beta functions are changed all around the ring and the compensation schemes start to depend on each other. Local compensation schemes, i.e. using only the adjacent three quadrupoles, must compromise either in beat or in tune correction, since four parameters would be needed for complete correction.

For the chosen structure the remaining offsets after local corrections are small enough to allow the superposition of single correction schemes. The parallel use of different or all IDs will then cause a beta beat of less than 10% and a tune shift of about .01.

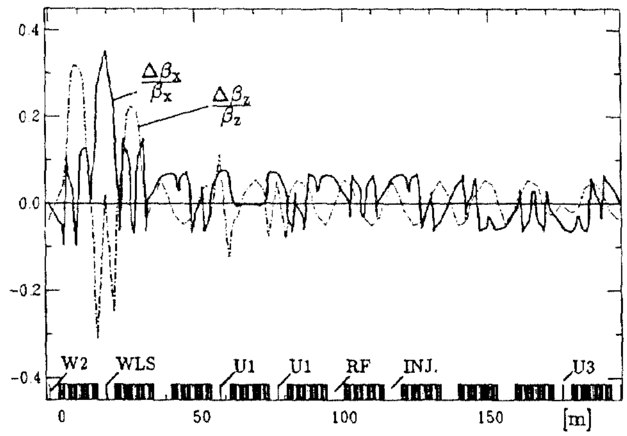

Fig. 2: The remaining beta beat after the superposition of the correction schemes for five typical IDs, including a 5 T wavelength shifter. ΔQ_x = .008, ΔQ_z = -.011.

In the case of the WLS, either a combined global/local correction scheme (a global tune correction would cause a change in the beta functions of < 7%) or a four quadrupole scheme, including the first quadrupoles in the adjacent straight sections, will be used. No clear advantage of either scheme could be determined by tracking. Fig. 2 shows the remaining effect for the simultaneous use of five insertion devices, including the WLS with a 4 quadrupole correction. The dynamic aperture of the bare lattice is practically maintained.

The non-linear fields of the IDs cause a change of size and direction of the tune shift with amplitude, which can be corrected by the two additional sextupole families in the straight section (chapter 4).

4. Reduction of particle losses

The maximum tune variation at BESSY II due to chromatic and amplitude effects will be limited by the integer resonances Q_x = 14.0, Q_z = 6.0, the $4Q_z$ = 25 resonance driven by the IDs, and Q_x = 14.333, driven by sextupole magnets. The amplitudes at which those tunes are reached determine the dynamic aperture.

Chromatic effects

A momentum acceptance of at least 3-4% with a sufficiently large dynamic aperture is one of the prerequisits for a good electron beam lifetime (Touschek effect, Bremsstrahlung). By introducing a third sextupole family in the dispersive section, the maximum tune shift of particles with a momentum deviation of 4% can be reduced by almost 40% to $\Delta Q_{x,z\ max}$ (±4%) < 0.07, (Fig 3).

The additional sextupole magnet also allows to treat horizontal against vertical tune shift with momentum, or momentum acceptance against transverse dynamic aperture, to achieve optimal lifetimes. These results are maintained when the sextupole families in the straight section are used.

Dynamic aperture

For the sextupole setting that achieves the optimum energy acceptance the dynamic aperture of the lattice is relatively small (10-15 mm in both planes). It can be greatly enlarged using the two compensation sextupole families in the straight section. These sextupoles are also used to restore the dynamic aperture after it has been reduced by the IDs.

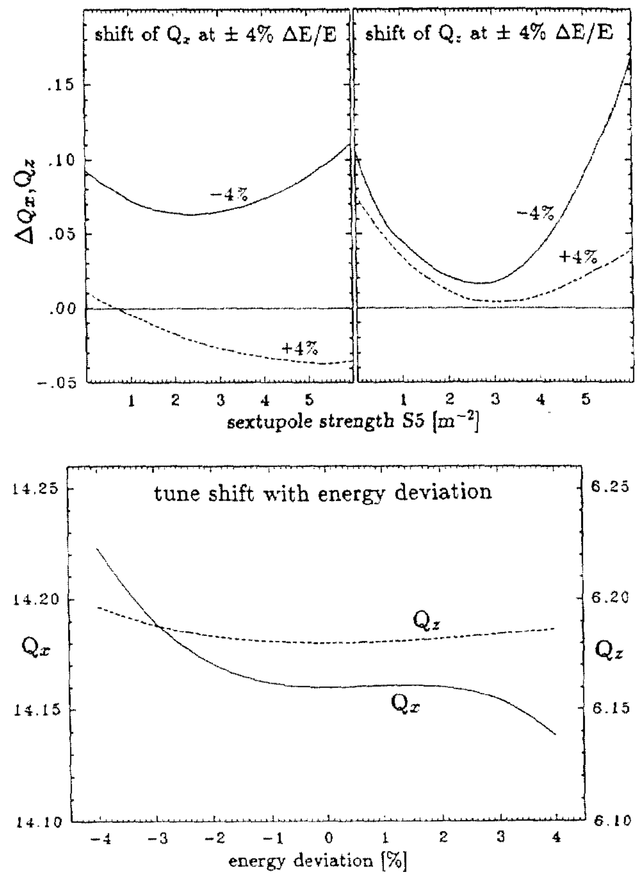

Fig. 3: The tune shift with energy deviation can be reduced to $\Delta Q_{x,z}$ < 0.07 at $\Delta E/E$ = 4% using three sextupole families in the achromatic section

Figure 4 shows the dependence of the horizontal and vertical dynamic aperture on the strength of the two compensation sextupole families in a contour plot. The smoothness of the maxima indicates a stable and continuous influence of these parameters. The sextupoles in the chromatic section are set to achieve an optimum energy acceptance.

In an alternative sextupole scheme (Fig. 5), all five sextupole families have been tuned in a way to minimize the amplitude dependent tune shift coefficients and to set the chromaticity $\xi_x = \xi_z = 0$; this still provides a small tune shift with energy (S5 = 1.8 m^{-2}). The tune variation is small, and the particles get finally lost due to fifth order resonances, which have not been observed in existing electron machines to our knowledge. Fig. 5 also shows the tune movement for particles with +-3% energy deviation and large amplitudes. The aperture of A_x^{min} = 26 mm and A_z^{min} = 22 mm is sufficiently large.

The influence of the insertion devices on the dynamic aperture can be seen in Fig. 6 for the undulator U3. The size and the direction of the tune shift with amplitude is changed, so that the critical resonances like Q_z = 6.25 are hit earlier. This change can not be corrected in all cases, but it can be influenced by the compensation sextupoles, and in most cases the dynamic aperture can be restored. In a contour plot like Fig. 4 the influence of the IDs would result in a shift of the maxima.

Errors in the lattice also cause a change in size and direction of the tune shift with amplitude. The main resonances driven by errors lie outside the region of interest in the tune diagram, so no 'break down' of the aperture occurs ([6]).

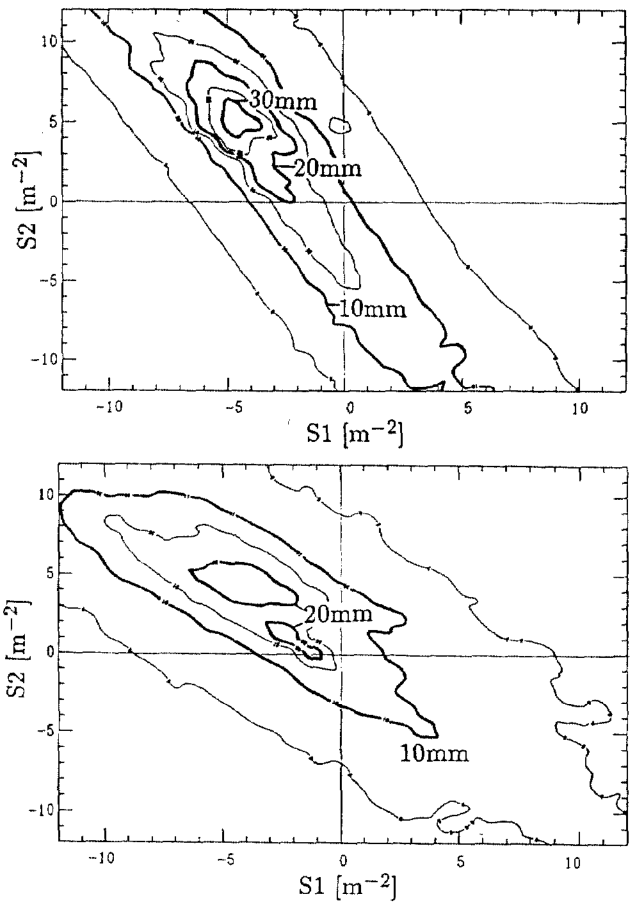

Fig. 4: A contour-plot of the horizontal (above) and vertical (below) dynamic aperture as a function of the compensation sextupole strengths indicates the well predictable influence of these parameters.

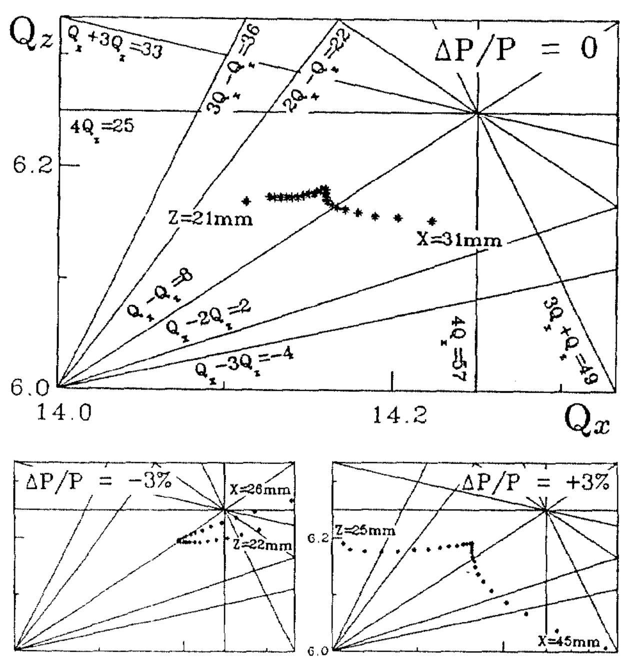

Fig. 5: With an alternative sextupole scheme the tune variation for large horizontal and vertical amplitudes is minimized for on-momentum particles, but also particles with ± 3% energy deviation obtain a satisfactory dynamic aperture.

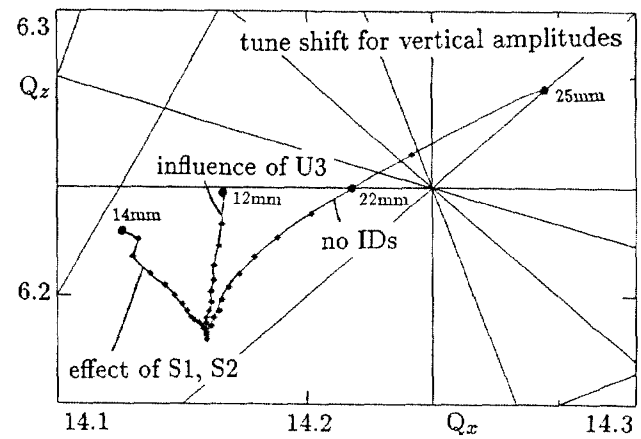

Fig. 6: The tune shift for large vertical amplitudes changes in size and direction when the undulator U3 is operated, and when the compensation sextupoles S1, S2 in the straight section are tuned.

5. Conclusion

It has been shown, that with the chosen lattice for BESSY II the linear effects of the insertion devices can be corrected locally to a degree which is expected to be comparable to the precision of the bare machine. The tune shifts of particles with large amplitudes and momentum deviation can be compensated to achieve a sufficiently large dynamic aperture, and the choice of the tune and the reduction of the tune variation also yields a good dynamic aperture in case of magnet errors and closed orbit deviations. The coincidence of all relevant effects and all manufactoring inaccuracies can hardly be realized in a computer model, and the achieved agreement between computer models and existing machines hardly encourages attempts in this direction [8, 9]. The presented lattice design therefore tries to provide a variety of parameters to correct the main lifetime limiting effects.

References

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