Lattice and Dynamical Behavior of the Light Source ANKA

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Abstract

ANKA, a 2.5 GeV light source will be built at the Research Center Karlsruhe, Germany. This source is dedicated to the fabrication of microstructures and X-ray analysis. For ANKA a structure with a twofold symmetry was chosen, resulting in two long (l=7m) and two short (l=4m) straight sections. Each achromat of 90 degree is composed of two DBA-structures which lead to a minimal emittance of 45 nmrad. Both DBA-structures are matched with quadrupole doublets leaving enough space for the installation of one rf-cavity. The circumference of the machine is 103.2 m.The working points are $Q_x = 6.85$ and $Q_y = 3.24$. These working points with only chromatic sextupoles lead to an acceptable dynamic aperture including the installation of different insertion devices (undulators, wigglers and wavelength shifters). The energy acceptance is larger then 2 % and the movements of the working points with energy and amplitude of the betatron oscillations are favorable.

1 INTRODUCTION

The ANKA-project [1], which will be built at the Forschungszentrum Karlsruhe (FZK), is designed to satisfy the needs of X-ray deep lithography, galvanoforming, and plastic molding (German acronym LIGA) as well as X-ray analysis, in particular, of microstructures. ANKA with an energy of $E_0 = 2.5\ GeV$ and a magnetic field of $B_0 = 1.5\ T$ in the bendings delivers radiation with a $\lambda_c = 0.2\ nm$ or $E_c = 6.2\ keV$. Furthermore ANKA should be a compact machine (the circumference should be around 100m) with a relatively low emittance (below 80 nmrad).

For the lattice of this machine we investigated different fourfold symmetry structures. The DBA-structure [2] with an achromat of 90 degrees results in an unacceptable emittance of 700 nmrad. The TBA structure for a 90 degree achromat with [3] and without combined function magnets [4] yields to emittances between 200 and 300 nmrad. Taking 4 bendings per achromat it is possible to reduce the emittance down to 50 nmrad. With the modified QBA-optics [6] the emittance is 45 nmrad and the double DBA-structure gives 80 nmrad. This can be reduced with a so called distributed dispersion function to 50 nmrad.

Inherent to the modified QBA-structure is the use of combined function magnets. To avoid the change of focusing within the bending magnet in the case of saturation it was chosen to take for ANKA the double DBA-structure

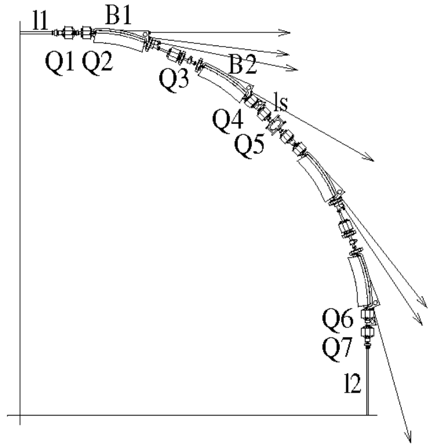

Figure 1: One half of the unit cell of the double DBA-structure (DDBA) adopted for the synchrotron light source ANKA.

(DDBA).

2 LATTICE OF THE LIGHT SOURCE ANKA

The layout of the DDBA-lattice for ANKA (one half of the cell) is given in fig.1. Bi ($i = 1 \ldots 4$) are the 22.5 degree bending magnets, Q3 performs the focusing to reach an achromatic arc and the doublets Q1,Q2 as well as Q6,Q7 perform the matching of the machine functions to the straight section. ls is a small straight section in the middle of the arc for the accommodation of the r.f.-cavity. 2·l1 (≈ 4 m) and 2·l2(≈ 6.8 m) are the straight sections. One is used for injection and three of them for the installation of insertion devices. The behavior of the machine functions within one cell (180 degree) are represented in fig.2 and fig.3 for the cases: with and without a distributed dispersion function. For both cases the working points are the same (Q_x=6.85 and Q_y=3.24).The principal parameters are summarized in tab.1,2 and 3. The physical aperture according to the dimension of the vacuum chamber (25 mm) in x-direction and 17 mm in the vertical resulting in the values: A_x(phys) = 33 mmrad and A_y(phys) = 11.5 mmrad.

Table 1: Main parameters of ANKA for both versions

Achromatic structure	DDBA	
Number of unit cells	2	
Nominal energy (GeV)	E	2.5
Circumference (m)	C	103.2
Beam current (mA)	I	200 (400*)
Coupling factor	c	0.02
Betatron tunes (Q_x/Q_y)	6.85/3.24	
Nat. energy spread	dE/E	$9.0 \cdot 10^{-4}$

* Upgrading at a later time.

Table 2: Parameters for the working point Q_x=6.85,Q_y=3.24 (achromatic arc).

Version	η=0.0	
Nat. emittance (nmrad)	$\varepsilon_x/\varepsilon_y$	88/1.7
Nat. chromaticity	ξ_x/ξ_y	-15.8/-8.0
Mom. com. factor	α	$8.6 \cdot 10^{-3}$
Beta functions (m/rad)		
– straight sections	β_x/β_y	18.8/6.9
– bending magnets	β_x/β_y	0.65/10.31
– Maximum value	β_x/β_y	18.9/20.34
Dispersion function (m)		
– straight section	η_{ss}	0.00
– bending magnet	η_{bm}	0.11
Source Size (mm)		
– straight section	$\Sigma_{xss}/\Sigma_{yss}$	1.29/0.11
– bending magnet	$\Sigma_{xbm}/\Sigma_{ybm}$	0.26/0.126

Table 3: Parameters for the working point Q_x=6.85,Q_y=3.24 (distributed dispersion).

Version	$\eta \neq 0.0$	
Nat. emittance (nmrad)	$\varepsilon_x/\varepsilon_y$	45/0.9
Nat. chromaticity	ξ_x/ξ_y	-14.4/-7.8
Mom. com. factor	α	$1.0 \cdot 10^{-2}$
Beta functions (m/rad)		
– straight sections	β_x/β_y	18.8/6.9
– bending magnets	β_x/β_y	0.59/9.4
– Maximum value	β_x/β_y	19.0/18.7
Dispersion function (m)		
– straight section	η_{ss}	0.55
– bending magnet	η_{bm}	0.14
Source Size (mm)		
– straight section	$\Sigma_{xss}/\Sigma_{yss}$	1.05/0.095
– bending magnet	$\Sigma_{xbm}/\Sigma_{ybm}$	0.21/0.091

3 DYNAMIC BEHAVIOR OF THE LATTICE

The dynamic aperture of ANKA with only chromatic sextupoles results in an acceptance of : A_x=65 mmrad and A_y=200 nmrad. Which are a factor 2 respectively 20 larger than as the physical ones. The energy acceptance is in the range -4 % < ΔE/E < 3.8 %. Which is four times more than the acceptance of the rf- system. The limits of the dynamical aperture as well as the energy acceptance is determined by the fact, that with an increasing amplitude of the betatron oscillations and energy deviation the working point moves to the resonance lines Q_x=7.0 and Q_y=3.333.

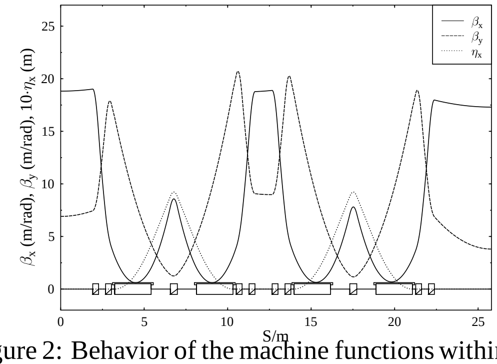

Figure 2: Behavior of the machine functions within the unit cell of the DDBA-Structure. The natural emittance for this acromatic solution is is 88 nmrad.

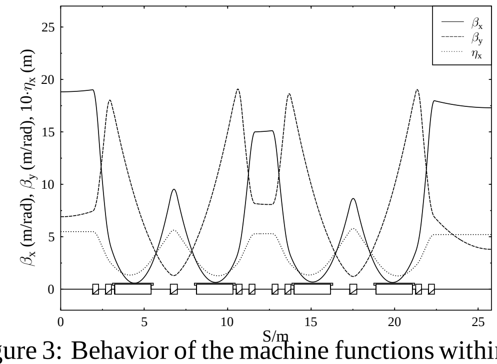

Figure 3: Behavior of the machine functions within the unit cell with the distributed dispersion function. The natural emittance goes down to 45 nmrad.

A reduction of the dynamic aperture and the energy acceptance is a consequence of misalignments and multipoles within the magnets. With closed orbit deviations of $\pm 0.5\ mm$ and the multipoles according to the ALS-quads [6] the energy acceptance reduces to $-2.3\ \% < \Delta\ E/E < 2.2\ \%$. The dynamical acceptance for this case (see fig.4) are A_x=48 mmrad and A_y=85 mmrad. These values are of a factor 1.5 (A_x) to 8 (A_y) higher than the physical apertures. The installation of different wigglers or wavelength shifters within the straight section influenced the dynamical aperture only by a small amount (less than 20 %).

The brilliance can be increased by using an optics with a distributed dispersion function (see fig.3). With this setting the dynamic aperture drops down to A_x = 21 mmrad and A_y=58 mmrad and the energie acceptance to -1.75 % < ΔE/E < 1.75 %.This means that the acceptance in the horizontal direction is 50 % the physical one. With the installation of harmonic sextupoles it is possible to optimize the dynamic aperture again. The strength of this sextupoles are 5 times smaller than the chromatic ones. Including closed orbit deviation (± 0.5mm) and higher harmonics of the quads the dynamic apertures are: A_x=42 mm·mrad and A_y = 74 mm·mrad for ΔE/E=±2%. The energy acceptance is larger than ± 3 %. These values are in the order of magnitudes as for the achromatic arc setting (see fig.2) with only chromatic sextupoles.

All calculations for the non linear behavior have been made with the code BETA [7], RACETRACK [8] and MAD [9]. Within 10 to 20 % the results of the codes agree with each other.

4 CHANGING THE WORKING POINT

In order to increase the brilliance more one has to move the horizontal tune to higher values. Therefore we investigated also the working point 2: Q_x=7.1 and Q_y= 3.16. By using only the chromatic sextupoles the acceptance in the vertical direction is high enough, but in the horizontal it is in the near of the physical one. It could be, that ANKA will run reliable with such a small acceptance. In order to get a safety margin one has to introduce the so called harmonic sextupoles in the region around the doublets Q1/Q2 and Q6/Q7.

The smallest emittance (44 nmrad) can be reached by using the distributed dispersion function. The dynamic aperture for this case, including harmonic sextupoles, higher multipoles in the quads and misalignment of the magnets with closed orbit corrections is given in fig.5 with the apertures A_x=54 and A_x=92 mm·mrad. The energy acceptance is -3 % $\leq$ ΔE/E $<$ 2.5 %. A comparison with fig.4 shows that the dynamical aperture of the relaxed optics (Q_x=6.85,Q_y=3.24) is roughly the same as for the optics yielding the smallest emittance of 44 nmrad.

5 CONCLUSION

For the storage ring ANKA the working point 1 (Q_x=6.85,Q_y=3.24) has with chromatic sextupoles a dynamical aperture which is a factor 1.5 (A_x) and 8 (A_y) higher as the physical one. The energy acceptance is a factor of 2 larger as that one given by the rf-system. Hence the dynamic behavior of ANKA looks favorable. To reach the smallest emittance one has to move to the working point 2 (Q_x=7.19,Q_x=3.15) and use the distributed dispersion lattice. With the introduction of harmonic sextuploes one reaches the same dynamic behavior as for the working point 1 (Q_x=6.85,Q_x=3.24).

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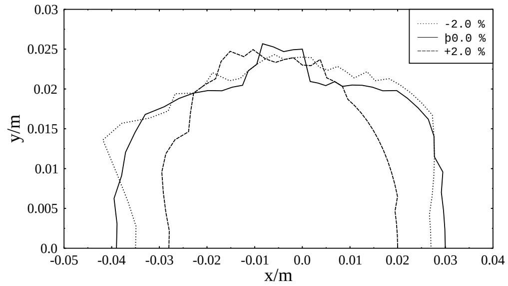

Figure 4: Dynamic aperture of ANKA for the working point 1 (Q_x=6.85/ Q_y=3.24) including only the chromatic sextupols. The higher multipoles of the quads and also a closed orbit distortion of 0.5 mm are included in the calculations

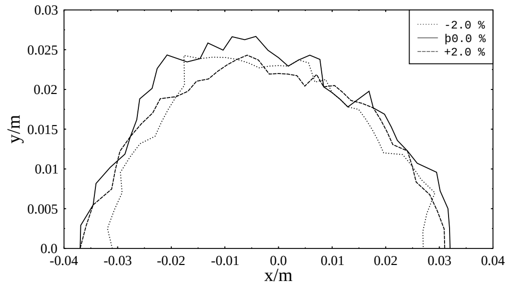

Figure 5: Dynamic aperture of ANKA for the working point 2 (Q_x=7.19/ Q_y=3.15,distributed dispesion function) with chromatic and harmonic sextupols. The higher multipoles of the quads and also a closed orbit distortion of 0.5 mm are included in the calculations.

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