Dynamic Aperture of the 2.5 GeV Synchrotron Radiation Source LISA

D.Einfeld #), D.Husmann+) , M.Plesko$)

#) Fachhochschule Ostfriesland, Constantiaplatz 4, D - 2970 Emden
+) Physikalisches Institut der Univ. Bonn, Nußallee 12, D - 5300 Bonn 1
$) Sincrotrone Trieste, Padriciano 99,I - 34012 Trieste

Abstract

LISA, a Light Source for Industrial and Scientific Application, has been proposed to be built in the Bonn region of Germany. For the lattice a modified "Quadrupole Bend Achromat " (QBA) will be used. The novel feature of this lattice is the application of two types of bending magnets with a vertical focusing component and different deflection angles to keep the radiation integrals small. The long bending magnets (20°) will be used in the arc of the achromat and the small (10°) are foreseen to perform the matching of the twiss functions from the arc to the straight sections without blowing up the emittance determined by the magnets in the arcs. With a sixfold symmetry, a circumference of 125 m an emittance smaller than 20 nm rad can be obtained. The natural chromaticities and the sextupole strength are moderate, the dynamic aperture is +/- 30 mm (100 σ_x and 170 σ_y), the momentum acceptance is more than +/- 9 % and the tune shift with amplitude is very promising.

I. INTRODUCTION

The synchrotron radiation source LISA, which has been presented first at the EPAC 1992 [1], is primarily foreseen for industrial applications. There is a strong demand to utilize synchrotron radiation for microlithography on thick layers in connection with the LIGA process [2], which needs a radiation spectrum around a critical wavelenght of 0.2 nm. This spectrum is being produced by 2.5 GeV electrons deflected in a magnetic field of 1.5 Tesla. For LISA a new lattice , the modified QBA-Optics, has been worked out. This lattice results in a compact storage ring with a quite low emittance. The complete LISA ring is composed of six achromats and straight sections of 4.6 m in lenght between them. The total circumference adds up to 124.8 m. The ring emittance at the energy of 2.5 GeV is calculated to be 20 nm rad which is a rather low value for such a machine and is due to the new QBA-lattice.

The small emittance is certainly not absolutely nècessary for the industrial application for LIGA, however, it makes this machine attractive for fundamental research as well.

II. LATTICE OF THE QBA-STRUCTURE

The LISA magnet ring consists of 6 achromats and a long straight sections between them. Each achromat is combined of 2 unit cells (as shown in Fig.1) and matching cells on both sides to match the optical functions to the conditions of the straight sections. The unit cell contains the bending magnet B_2 (20°) and the adjacent quadrupoles Q_M; the matching section contains the dipole B_1 (10°) and the 4 adjacent quads too.The dipoles B_2 bend the orbit by an angle φ while those (B_1) in the matching cells bend the beam only by half of the angle φ. The curves of the twiss functions within an achromat are given in Figure 2.

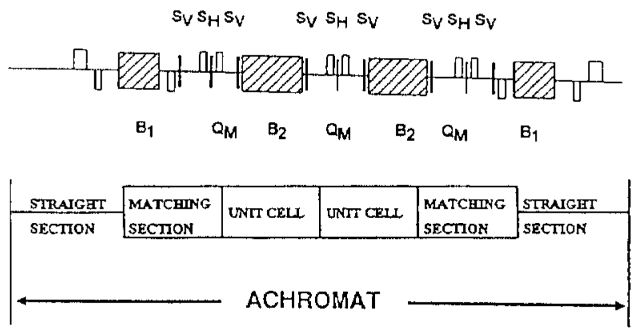

Figure 1. Composition of a QBA - achromat and the arrangement of magnets within a unit cell

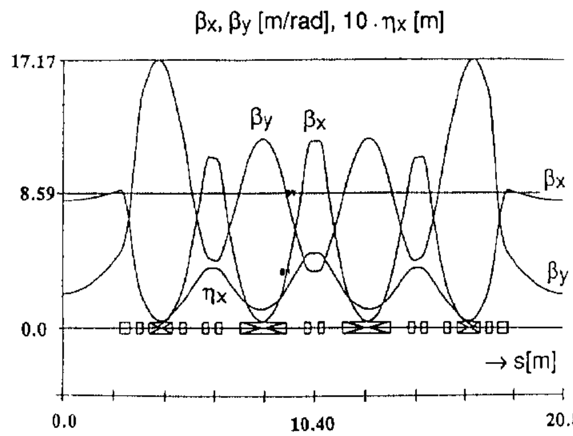

Figure 2. The Twiss functions and the lattice of the proposed LISA storage ring

The performance of the storage ring is characterized by the parameters: emittance, betatron tunes, chromaticities, partition numbers and the momentum compaction factor. The emittance of the QBA-structure is mainly determined by the unit cell, which has for a certain strength $k_M{}^*$ the minimized value ε_{x0}=20 nm rad. For k_M-values larger than $k_M{}^*$ the emittance increases drastically and for k_M-values smaller than $k_M{}^*$ it increases slowly . The detailed results are given in the report [3].

The chromaticity in the vertical direction is moderate, but in the horizontal direction it increases significantly with k_M-values larger than $k_M{}^*$ (which yields the lowest emittance).

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The chromaticities at the lowest emittance are moderate and it should be possible to operate the unit cell at this value of k_M^*. An advantage of the lattice is that together with a reduction of the chromaticity by a factor of 2 the emittance only increases by a factor of 1.5.

The betatron tune Q_x in the horizontal plane is almost exclusively determined by the strenght of the horizontal focusing quad Q_M of the unit cell. The vertical betatron tune Q_y is mainly determined by the strenth of the gradient in the bending magnets (B_1 and B_2)and only slightly dependent on the one of the quad Q_M. Therefore Q_x and Q_y are more or less independently controlled by either the k_M-value of the quad Q_M or the gradient of the bending magnets B_2 and B_1. Some working points are shown in the tune diagram in Fig.3. As the vertical tune of one achromat is close to 0.5 it was difficult to find both, the working point of the ring and that of the single achromat, far from half integer and third integer resonances. Several lattices with acceptable working points and chromaticities were tested in further optimization studies. The position of the chromaticity correcting sextupoles were optimized by use of the computer code CATS [4]. There are only two families of sextupoles but there is more than one sextupole of each family in an achromat. Thus a partial cancelling of higher order terms has been achieved. A sufficiently large dynamic aperture for almost all lattices studied has been obtained by a proper positioning of the chromatic sextupoles.

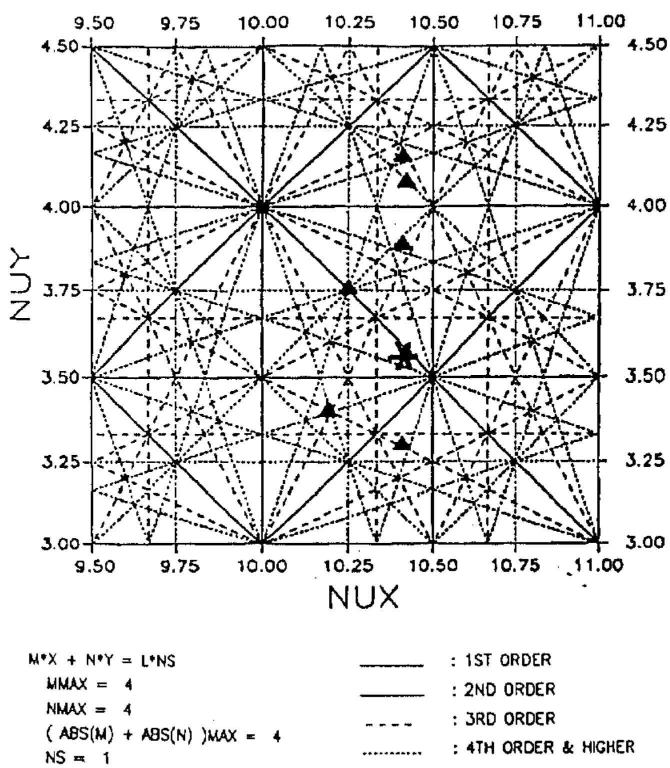

Figure 3. Tune diagramm of the modified QBA-optics with investigated working points. The choosen point Qx=10.413 and Qy=3.559 is indicated by a star

III. DYNAMIC APERTURE

The dynamic aperture calculated for the optimized chromatic sextupole layout (Figure 1) is shown in Figure 4 for energy deviations from -9 % to +9 %. The tracking has been performed with 1 particle for 100 turns. To confirm the results 4 particles were tracked for 5000 turns. The calculations have been carried out with the code RACETRACk [5] and checked with the codes CATS [4], MAD [6] and BETA [7].

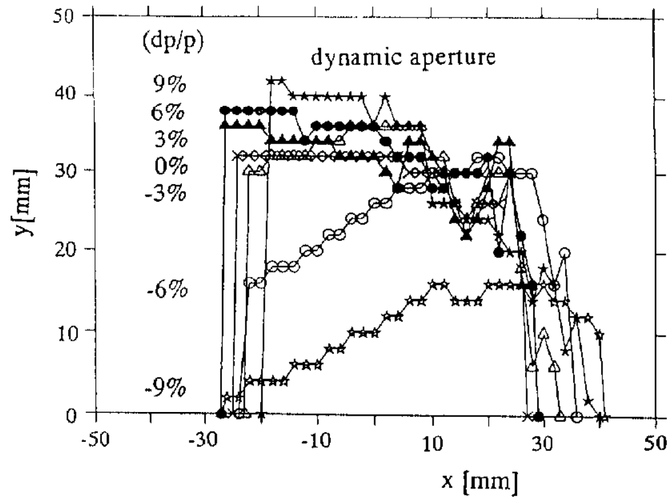

Figure 4. Results of tracking calculations of the dynamic aperture of the modified QBA-structure for 1 particle and 200 turns

For particles at nominal energy the dynamic aperture extends from -27mm to +27 mm in the horizontal direction (100 σx) and stays constant about 30 mm in the vertical direction (170 σy, coupling 0.5 at about within the entire range). This gives sufficient space for the injection process and for a long beam lifetime. There is no reduction of the phase space at energy deviations of +/- 3 %. A reduction only occurs at energy deviations below - 6 %. But even at - 9 % the dynamic aperture is still surprinsingly large. Compared to other 3[rd] generation light sources the dynamic aperture of this QBA-lattice is very large.

The betatron tunes are only weakly dependent on the corresponding oscillation amplitudes only as is shown in Figure 6 . The tune increases quadratically with the amplitude to the upper limit of the dynamic aperture, indicating that the second order approximation which is used in CATS is valid within the entire range.

The dependence of the tune shift on the momentum is shown in Figure 6. It is remarkable that a closed solution still exists up to a momentum deviation of +/-9 %. According to the design of the rf-system only particles with a momentum offset of +/- 3 % in the maximum will be captured. Therefore only this momentum interval is important and the tune within this range is almost constant.

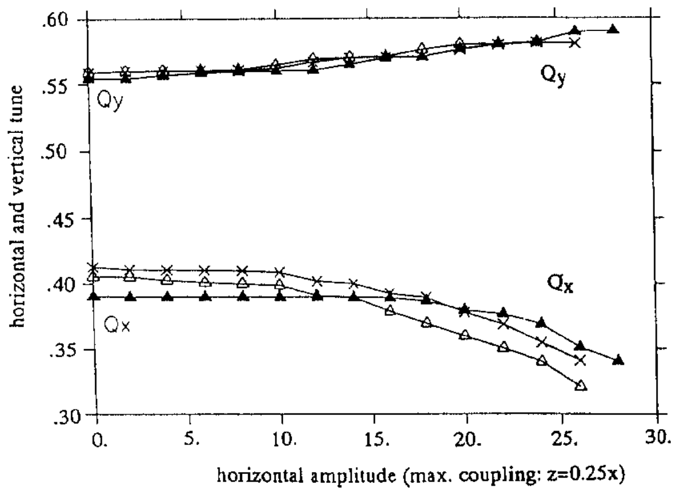

Figure 5. The fractional tune of LISA as a function of the initial amplitude for on energy particles (crosses), and dp/p = 3 % (open triangles), and + 3 % (full triangles), respectively.

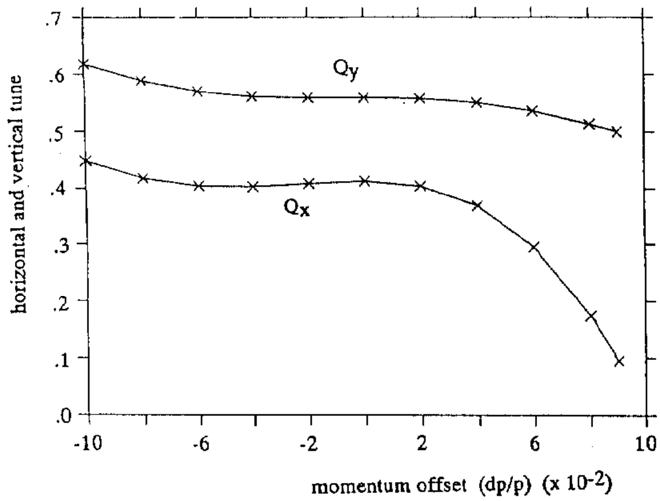

Figure 6. The fractional tune of LISA as a function of particle energy deviation

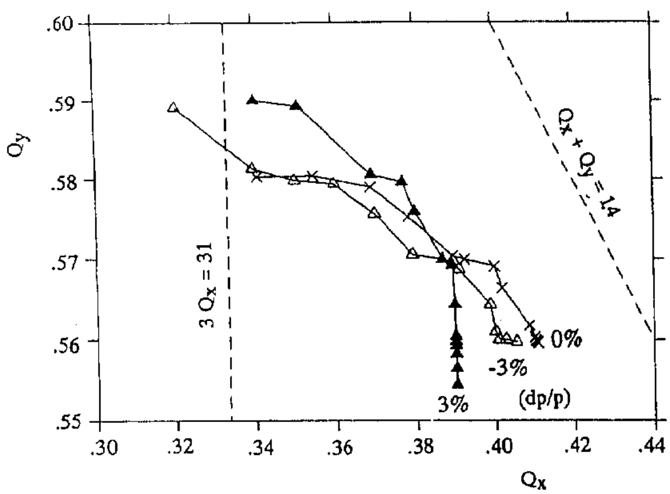

Figure 7. Working point shift with amplitude and momentum offset. Indicated are second and third order resonances.

Figure 7 shows the tune shift with increasing amplitude at the nominal energy and for a +/- 3 % momentum deviation. Each point represents an increase of 2 mm in the horizontal and of 1.4 mm in the vertical amplitude. No dangerous lines are crossed.

IV. COMPARISON WITH OTHER MACHINES

There are 2 machines of the 2nd generation running at roughly the same energy: the Daresbury machine "SRS2" at a nominal energy of 2 GeV and the "NSLS XRAY" ring with an energy of 2.5 GeV. SRS2 has a FODO-structure, 22.5° bending magnets, a circumference of 96 m and an emittance of 100 nm rad. Scaling SRS2 to the same energy and deflection angles as for LISA the emittance increases to 110 nm rad, which is larger by a factor of 5.5 compared to LISA. The "NSLS XRAY" source has a DBA-structure with 22.5° bending magnets, a circumference of 172.8 m and an emittance of 100 nm rad. Using 20° bending magnets would reduce the emittance to 70 nm rad, which is a factor of 3.5 larger than for LISA. According to the criteria LISA is a 3rd generation light source.

Furthermore LISA can be compared to the machines of the 3rd generation: ALS, ELETTRA and the POHANG Light Source. They are all designed to run at an energy of 2 GeV and have an emittance around 6 to 9 nm rad at this energy. Scaling this value to the energy and the bending angle of LISA results in 40 to 65 nm rad which is more than twice the LISA emittance.

The low emittance of the modified QBA-lattice has been observed even more evidently at larger rings, which has been demonstrated in another contribution to this conference [8].

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