The Low Emittance 2.5 GeV Synchrotron Light Source LISA

D. Einfeld*), J. Hormes), D. Husmann**) and F. Anton***)**

*) Fachhochschule Ostfriesland, Constantiaplatz 4, D-2970 Emden
**) Physikalisches Institut, University of Bonn, Nussallee 12, D-5300 Bonn
***) Siemens AG, Friedrich-Ebert-Straße, D-5060 Bergisch-Gladbach

ABSTRACT

LISA, a Light source for Industrial and Scientific Applications, has been proposed to be build in the Bonn region recently. Due to the intention to use the source above all for the LIGA (Lithographie, Galvanik, Abformtechnik) method to produce micromechanical structures the critical wavelength of the synchrotron radiation spectrum is foreseen to be 0.2 nm. Therefore the electron energy and the field strength of the ring dipoles have been chosen to be 2.5 GeV and 1.5 T respectively. It is proposed to make use of a modified "quadrupole bend achromat" (QBA) lattice. The novel feature of this lattice is the application of two types of bending magnets of different lengths, i.e. different bending angels. Moreover these mangnets are combined function magnets to provide a vertical focusing. 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 level of 2.5 GeV is calculated to be 20 nm rad which is a rather low value of such a machine and is due to the new QBA lattice. The natural chromaticities and the compensating sextupole strength are moderate, the dynamic aperture is large as well as the momentum acceptance (>9%).

1. INTRODUCTION

The synchrotron radiation source LISA [1] is primarily foreseen for industrial applications. There is a strong demand of industry to utilize synchrotron radiation for microlithography on thick layers in connection with the LIGA process [2]. LISA has been proposed in order to support the still necessary basic research in this field on a larger scale in Germany.

The LIGA microlithography needs a radiation spectrum around a critical wavelength of 0.2 nm. The synchrotron radiation spectrum being produced by electrons of an energy of 2.5 GeV passing a normal bending magnet at a field strength of 1.5 T is suitable for the task. A circulating current of 150 mA at a lifetime of 10 hours fulfills all demands. A beam emittance up to 100 nm rad is acceptable. Above all other demands a machine for industrial applictions should be reliable and handy in operation.

The small emittance of the LISA ring - which certainly is not absolutely necessary for the industrial application LIGA - however makes this machine attractive for fundamental research as well.

2. LATTICE OF LISA

As lattices for synchrotron light sources the DBA- and TBA-structures are well known and discussed in many papers [3] [4] [5]. The QBA-optic [7] with 4 quadrupoles in an achromat is only once investigated and a storage ring with such a lattice has never been built. The investigation of the TBA- and QBA-structures shows [6] that the emittance is determined by the first and the last bending magnet (matching magnets) of the achromat. That means: These magnetic structures are DBA- dominated and it is not possible to reach the minimal emittance according to the mismatching of the optic functions $\beta_x(s)$, $\beta_y(s)$ and $\eta(s)$ from the arc to the straight sections. The contribution of the outer magnets to the H-functions of the emittance is 86% in the case of a TBA and 75% for a QBA lattice.

Quite different is the behavior of a modified QBA structure [6] which is proposed for the planned synchrotron light source LISA [1]. LISA is a 2.5 GeV electron storage ring with rather compact dimensions (i.e. a circumference of about 120 m). Matching the Twiss functions to an outer dipole with a deflection angle of $\Phi/2$ should force a smaller increase in the emittance by mismatching, because the differences between the existing and the matching conditions are not as large. The matching with a dipole of an angle $\Phi/2$ has been perfomed firstly for the storage ring DELTA [8] and outlined by Jackson [5].

The second advantage of the halved deflection angle in the outer dipole is that its contribution to the emittance is small (in the ideal case it is reduced to 15%) because the emittance is proportional to the third power of the deflection angele. Consequently, this structure is really determined by the dipole in the middle of the achromat, which gives the smallest emittance. Hence the ideal emittance of the modified QBA structure is smaller by a factor of 3 to 4 than that for a DBA or TBA structure.

The lattice of our proposed modified QBA structure consists of two unit cells accompanied on each side by a matching section followed by a straight section (figure 1). The dipoles within the unit cell have a deflection angle of Φ, whereas the ones in the matching section deflect by $\Phi/2$. In order to get the desired shape of the Twiss functions in the unit cell a bending, a focusing and a defocusing magnet are needed. This can be achieved by four quadrupoles and a dipole [8] or by two quadrupoles and a bending magnet with a superimposed quadrupole field to defocus the beam horizontally (figure 2). The unit cell with a defocusing bending magnet has been chosen in our case because it has a twofold advantage:

1) the number of magnets per achromat is reduced;
2) the horizontal partition number is larger than 1 and thus reduces the emittance.

In order to obtain the minimal emittance, a strength $k_f = 2.2225\ \mathrm{m}^{-2}$ for the 0.25 m long focusing quadrupole and a k_m value of $0.3365\ \mathrm{m}^{-2}$ for the defocusing bending magnet have been chosen. The performance of the achromat is mainly determined by the unit cell. A hypothetical 2.5 GeV storage ring composed of 18 unit cells (20 degree bending angle each) yields an emittance of $20\ \pi$ nm. The horizontal tune is determined by the k_f value of the quadrupole, while the k_m value of the bending magnet determines the vertical tune. Hence both directions are uncoupled. An advantage of the lattice is that by a twofold reduction of the chromaticity the emittance will only increase by 50%.

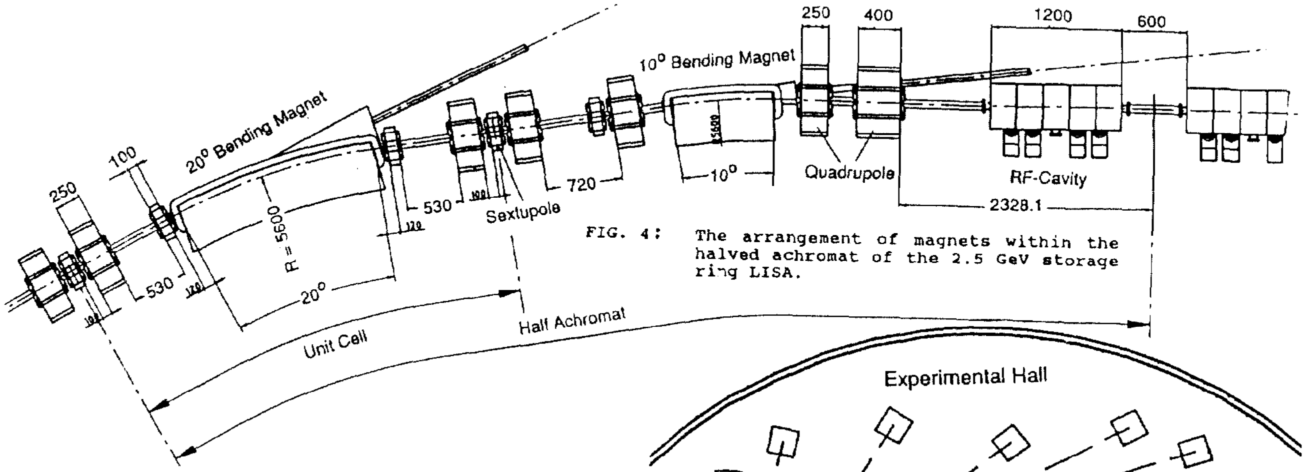

FIG. 4: The arrangement of magnets within the halved achromat of the 2.5 GeV storage ring LISA.

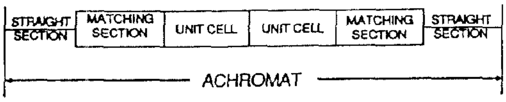

Fig. 1: The QBA achromat's inner structure.

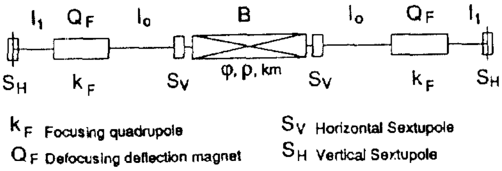

Fig. 2: The unit cell of the modified QBA lattice.

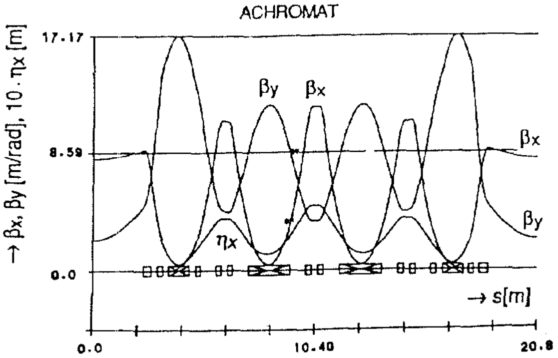

Fig. 3: The Twiss functions and the lattice of the proposed LISA storage ring.

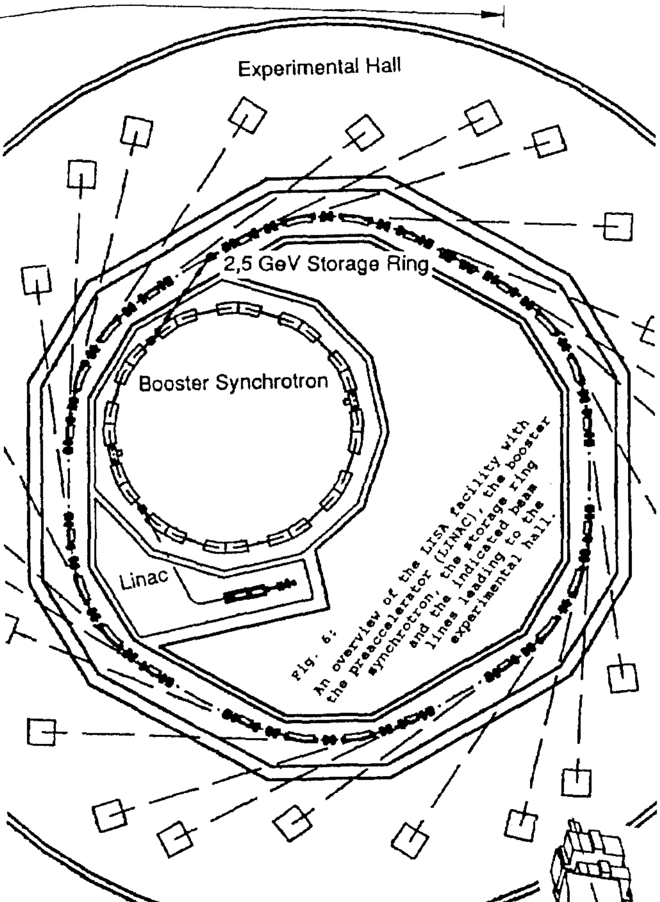

Fig. 6: An overview of the LISA facility with the preaccelerator (LINAC), the booster synchrotron, the storage ring and the indicated beam lines leading to the experimental hall.

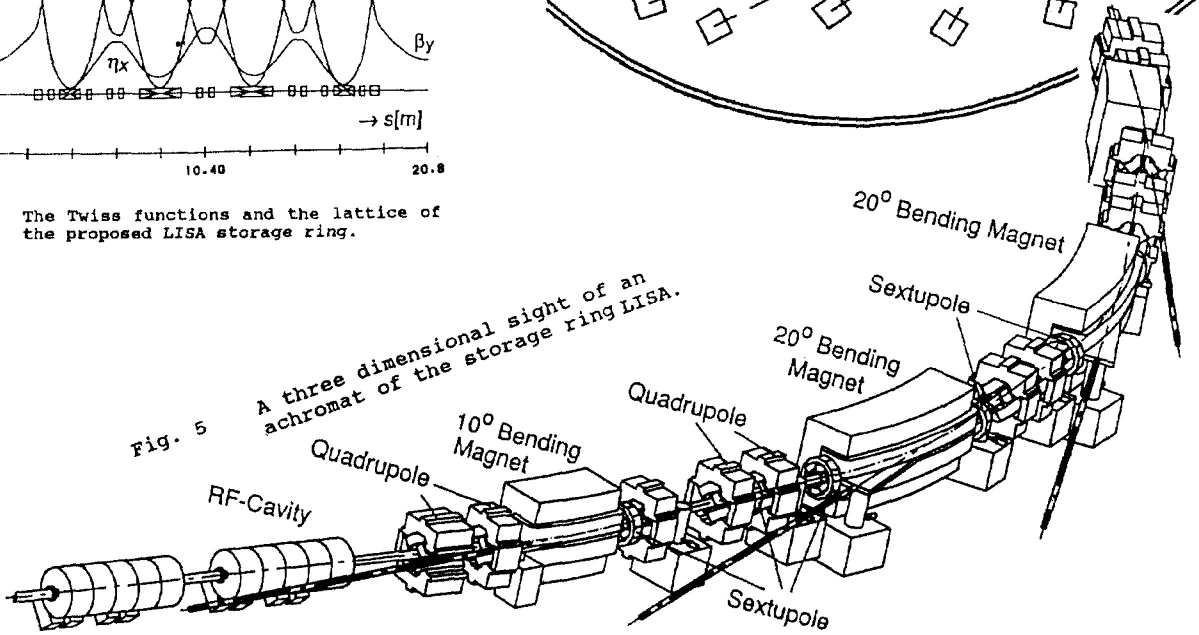

Fig. 5 A three dimensional sight of an achromat of the storage ring LISA.

Altering the distance between the bending magnet and the quadrupole does not change the behavior of the cell significantly, therefore the distance between the quadrupoles and the magnet was fixed to 0.75 m in order to have enough room for the steerers and the monitors.

Four quadrupoles are required in the matching section in order to match the Twiss functions to the desired values within the straight section. By changing the strengths of the quadrupoles, which surround the straight sections one can change the working point over a range of ± 0.5 in both planes by keeping the emittance constant and the values of the betatron functions within the straight section acceptable.

Since the vertical tune of one achromat is close to 0.5, some care has been needed to find both the working point of the ring and the single achromat's working point far from half-integer and sextupoles resonances. Several lattices with acceptable working points and chromaticities has been studied for further optimization. There are only two families of sextupoles but there is more than one member of a family in an achromat.

Finally a lattice was chosen which gave the best compromise between a large dynamic aperture and a safe working point [6]. The layout of a 60 degree achromat with its Twiss functions is represented in figure 3. The arrangement of the magnets within one half of an achromat is shown in figure 4. The main parameters of this QBA lattice are summarized in table 1.

3. THE SYNCHROTRON LIGHT SOURCE LISA

Planned light sources should have enough space for inserting wigglers or undulators in a later stage. For LISA a medium size storage ring it was chosen to have 6 straight sections with a lenght of 4.6 m as shown in figure.4. With this sixfold symmetrie the storage ring exists of six 60 degree achromats as presented in figure 5, which gives an overview of the whole facility.

The emittance of the storage ring is 20π nm rad, which is about five times less than the emittances of existing rings with compareable circumferences (see reference [9] for data on light sources). With respect to the ideal minimal emittance of the modified QBA structure, one sees that the emittance achieved is still larger by a factor of 3.6. However, it is already below the ideal emittance of the DBA structure and below the achievable emittance of the TBA structure.

The emittance of the ring composed only of unit cells was 20 π nm rad, too. That means that the emittance is determined mainly by the dipoles of the unit cell and not by the outer matching dipoles. Another lattice where the deflection angle of the dipoles has been changed from 10°/20° (matching dipole / unit cell dipole) to 11°/19° had an emittance of 15 π nm rad - a reduction that is not neglgible.

STORAGE RING	
Achromatic structure	QBA
Nominal energy (GeV)	2.5
Superperiod	6
Circumference (m)	124.8
Mean radius (m)	19.86
Max. current (mA)	150
R.F. Frequency (MHz)	500
Harmonic number	208
Quantum lifetime (h)	10
Natural emittance (π nm rad)	20
Natural energy spread (%)	0.1
Betatron tunes Q_x/Q_y	10.416/3.558
Natural chromaticities ξ_x/ξ_y	-21.24/-9.80
Momentum compaction factor	$0.56*10^{-2}$
Beta functions	
Horizontal (max/min)	11.91/0.41
Vertical (max/min)	17.17/2.18
Straight section (max/min)	8.11/2.18
Maximum dispersion (m)	0.466
Number of dipole magnets (10°/20°)	12/12
Dipole length (m) (10°/20°)	0.9774/1.9548
Bending radius (m)	5.60
Bending field (T)	1.50
Gradient (T/m) / field index	2.8266/10.553
Number of quadrupoles	12/60
Length of quadrupoles (m)	0.4/0.25
Quadrupoles families	5
Gradient (T/m) / strength (m^{-2})	20/2.40
Number of sextupoles	54
Lenght of sextupoles (m)	0.1
Sextupole families	2
Sextupole parameter, S=B/R2 (T/m^2)	750
BOOSTER SYNCHROTRON	
Magnetic structure	Comb. function
Injection energy (MeV)	20
Extraction energy (GeV)	1-2
Repitition rate (Hz)	10
R.F. Frequency (MHz)	500
Bending field (B_{max}/[T])	1.0
Max. current (mA)	20
PREACCELERATOR	
Energy linac (MeV)	50
R.F. Frequency (GHz)	3
Pulse current (mA)	10
Repitition rate (Hz)	10
SYNCHROTRON RADIATION	
Bending magnet (B_0 = 1.5 T)	
Critical wavelength (nm)	0.2
Crit. photon energy (keV)	6.23
Wavelenght shifter	
Critical wavelength (nm)	0.073
Crit. photon energy (keV)	17.041

Table 1: Parameters of the storage ring LISA

References

[1] LISA, Vorschlag für den Bau eines Speicherringes zur industriellen Nutzung der Synchrotronstrahlung im Raum Bonn, Oktober 1991

[2] E. W. Becker and W. Ehrfeld, Das LIGA - Verfahren - Microfertigung durch Röntgentiefenlithographie mit Synchrotronstrahlung, Galvanoformung und Kunststoffabformung, Phys. Bl. 44, 166, 1988

[3] R. Maier, High Brilliance Lattices, CERN 89-01, 89 (1989)

[4] A. Ropert, High Brilliance Lattices and the Effects of Insertion Devices, CERN 90-03, 158 (1990)

[5] A. Jackson, A Comparison of Chasmann-Grenn and Triple Bend Achromat Lattices, Particle Accelerators, Vol 22, 111 (1987)

[6] D. Einfeld and M. Plesko, "A modified QBA Optics for Low Emittance Storage Rings", Workshop on the 4th Generation Sources, Feb 24-27, 1992, SSRL/Slac, Stanford USA

[7] K. Tsumaki, R. Nagaoka, H. Tanaka, K. Yoshida and M. Hara Lattice Comparison for the 8 GeV Synchrotron Radiation Source, 1989 Particle Acc. Conf. Chicago, March 20-23

[8] Delta Status Report 1990, University Dortmund

[9] J. Murphy, Synchrotron Light Source Data book, BNL 4233, Brookhaven National Laboratory