A Dedicated Synchrotron Light Source for Micromechanics

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ABSTRACT

The LIGA process has become an accepted technology for fabrication of three-dimensional microstructures. The main process step of this technology is the deep X-ray lithography with synchrotron radiation (SR). In order to get a good aspect ratio the critical wavelength of the SR has to be 0.2 nm. Creating the radiation in a normal bending magnet with a flux density of 1.65 T the electron beam must have an energy of 2.36 GeV. For the generation of this characteristic SR a design of storage ring with a fourfold symmetry is proposed. Each quadrant has a DBA structure with 2 quadrupoles for matching the betatron functions to the desired values within the straight sections. Both the bending magnets and the quadrupoles of the DBA arc are split in order to insert the sextupoles. The ring has a circumference of 70.0 m with an emittance of $7{*}10^{-7}$ m*rad. The design allows the insertion of two wigglers at a later stage each with a length of 3 m.

1. INTRODUCTION

For the fabrication of three-dimensional microstructures the LIGA process has been developed at the Karlsruhe Nuclear Research Center (KfK) [1].

The LIGA process is based on a combination of X-ray lithography, electroforming and replication techniques. The maximum structural height of LIGA microstructures is several hundred micrometers, while the minimum lateral dimensions are on the order of one micrometer or even less. Due to the high parallelity of the synchrotron radiation and the high selectivity of the developer specially tailored to PMMA, which is used as X-ray sensitive material, submicron accuracy over the total height of the microstructures and vertical walls can be achieved.

As the dose absorbed in PMMA is allowed to vary from top to bottom by not more than a factor of 5 and as the depth of penetration increases with decreasing wavelength, synchrotron radiation with a very short characteristic wavelength is needed to pattern thick resist layers. A wavelength of 0.2 nm is ideal. In the following a dedicated SLS for this process, planned to be built at KfK in the near future, is described.

2. PARAMETER OF STORAGE RING

The requirements of a synchrotron light source dedicated to the LIGA-process are:

- Critical wavelength $\lambda_c = 0.2$ nm
- Current of stored beam $I \geq 100$ mA
- Opening angle of radiation $\theta_{max} \leq 0.35$ mrad

Besides these demands, the synchrotron light source should be easy to handle, reliable and cost-effective in operation. We have therefore chosen normal conducting bending magnets and kept the number of components in the storage ring to a minimum. To obtain a current of I = 100 mA the use of a preaccelerator without a booster synchrotron is foreseen and ramping the beam in the storage ring to the nominal energy. According to the experiences at the storage rings Aladdin (1 GeV) and Max I (560 MeV) the injection energy should be larger than 200 MeV. To have some margin we propose a linac with an energy of 300 MeV and a separated function storage ring.

The critical wavelength of the synchrotron spectrum is a function of the magnetic flux density B and the energy E. To get a compact light source the flux density within the bending magnets should be as high as possible. We think a field of about 1.6 T is manageable and have therefore chosen the following set of main parameters to reach $\lambda_c = 0.2$ mm.

- Magnetic flux density $B_0 = 1.6285$ T
- Nominal energy $E_0 = 2.3923$ GeV
- Bending radius $R_0 = 4.9$ m

The opening angle of the synchrotron radiation θ_γ emitted in the frame of one electron is $1/\gamma$. With an energy of 2.4 GeV the corresponding angle is 0.2 mrad. The opening angle of the synchrotron radiation, emitted from an electron beam and enlarged due to the emittance ε_z, is given by:

$$Q_{max} \quad Q_\gamma^2 + \varepsilon_z \gamma_z \ , \quad \gamma_z = \frac{1 + \alpha^2}{\beta_z}$$

α, β and γ are the + Twiss parameters of the beam. With $\gamma_z \approx 0.5$ (average value of different calculations) the emittance ε_z of the stored beam in the vertical direction should be smaller than:

$$\varepsilon_z \ \Theta^2_{max} - \Theta_\gamma^{\,2} \approx 0.09 \text{ mm mrad}$$

Table 1:Parameters of the KfK storage ring

STORAGE RING	
Achromamatic structure	DBA
Nominal energy (GeV)	2.4
Superperiod	4
Circumferance (m)	69.6
Mean radius (m)	11.08
Max. current (mA)	100
R.F. Frequency (MHz)	500
Harmonic number	116
Quantum lifetime (h)	8
Natural emittance (mm mrad)	0.7
Natural energy spread (%)	0.1
Betatron tunes (Q_x/Q_y)	3.153/1.389
Natural chromaticities ξ_x/ξ_y	-4.9/-2.3
Momentum compaction factor	0.05
Beta functions	
Horizontal (max/min)	22.0/1.40
Vertical (max/min)	280/2.14
Maximum dispersion (m)	2.25
Number of magn (22.5°)	16
Dipole length (m)	4.9
Bending radius (m)	4.9
Number of quadrupoles	8/16
Length of quadupoles (m)	0.2/0.25
Quadrupoles families	5
Gradient (T/m) / strength (m^{-2})	21.0/2.46
Number of sextupoles	12
Length of sextupoles (m)	0.1
Sextupole families	2
Sextupole parameter, S = B/R2 (T/m^2)	125
PREACCELERATOR	
Energy linac (MeV)	300
R.F. Frequency (GHz)	3
Pulse current (mA)	10
Repitition rate (Hz)	10
SYNCHROTRON RADIATION	
Bending magnet (B_0 = 1.64 T)	
Critical walvelength (nm)	0.2
Crit. photon energy (keV)	6.23
Wavelength shifter (B = 4.1 T)	
Critical walvelength (nm)	0.073
Crit. photon energy (keV)	17.041

The emittance of the stored beam is determined by the magnetic coupling k between the vertical and horizontal direction. With ε_0 the normalized emittance, the vertical emittance is given by:

$$\varepsilon_z = \frac{k}{1+k} \cdot \varepsilon_o$$

and it follows for the normalized emittance a value of

$$\varepsilon_o = \frac{1+k}{k} \cdot \varepsilon_z = 0.9\ mm\ mrad$$

This is a relatively high value. The emittance is mainly given by the energy ($\sim E^2$) and the deflection angle of the bending magnets ($\varepsilon_z \sim \phi^3$). According to the large emittance it is possible to build a compact light source because the deflection angle too can be relatively large. A simple DBA-lattice with an achromat of ϕ = 90 degrees can meet the requirements with respect to the emittance.

3. LATTICE OF STORAGE RING

Different lattices for this compact synchrotron light sources have been investigated: TAB (triple bend achromat), MBA (multiple bend achromat) and DBA (double bend achromat). From these different lattices it follows that the DBA structure gives the most compact solution and the parameters which determine the storage ring: tunes chromaticity, dynamic aperture, tune shift with momentum, and amplitude have for the DBA-structure reasonable values.

In order to get a large dynamic aperture and small sextupole strengthes the 45 degree magnet and the quadrupole between the magnets are splitted. The sextupoles for chromatical compensation can be inserted between the bending magnets (vertical sextupole) and the quadrupoles. At these positions the difference between the β_x and β_y-functions are largest and hence the sextupole strengths are small.

Tho whole facilty with storage ring, injector, beam lines and experimental hall is represented in fig. 1, the 90°-achromat with the splitted magnets is shown in fig. 2, the Twiss-functions β_x, β_y and η_x are give in fig. 3. The modified lattice with the corresponding Twiss-function for inserting a wriggler at a later stage is given in fig. 4. The resonance diagram is given in fig. 6 and the dynamic apterture for momentum offsets ±3% is representet in fig. 5. The dynamic aperture has values of ± 40 mm within the energy range of ±3% these are really sufficient because the physical aperture is smaller.

4. REFERENCES

[1] P. Bley, J. Göttert, M. Harmening, M. Himmelhaus, W. Menz, J. Mohr, C. Müller, U. Wallrabe The Liga Process for the Fabrication of Micromechanical and micro optical Components MICRO SYSTEM Technologies, 91, Berlin Nov.91

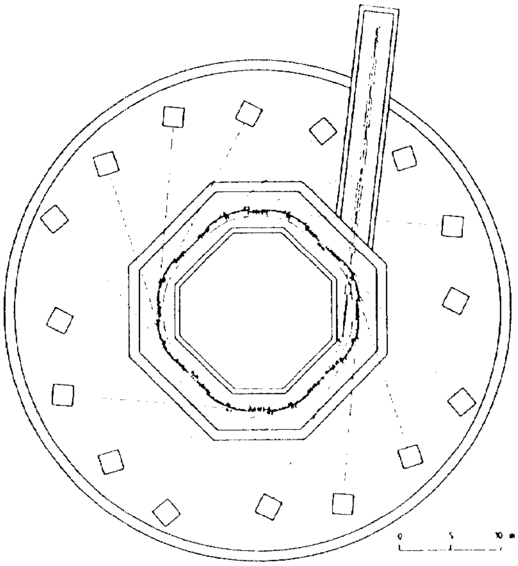

Fig. 1: An overview of the Karslruhe LIGA facility

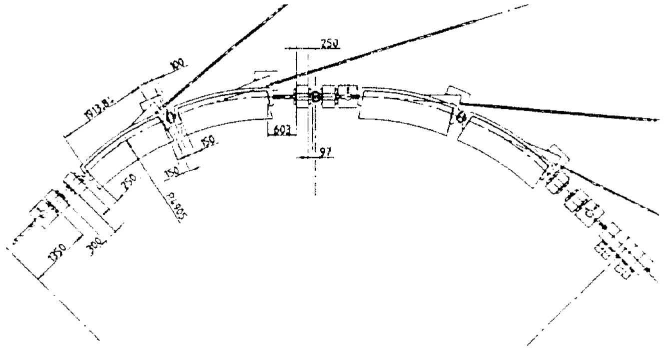

Fig. 2: The DBA lattice

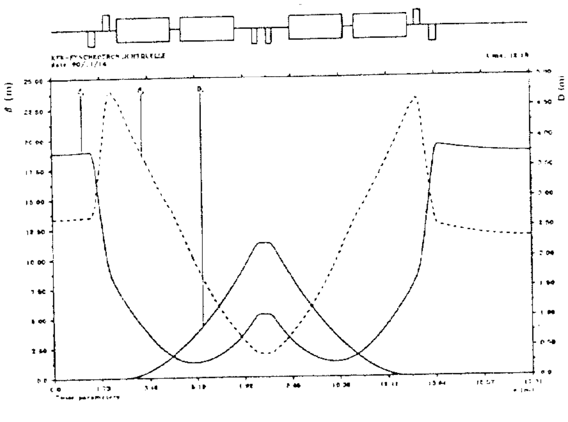

Fig. 3: Twiss functions and lattice of the KfK LIGA storage ring

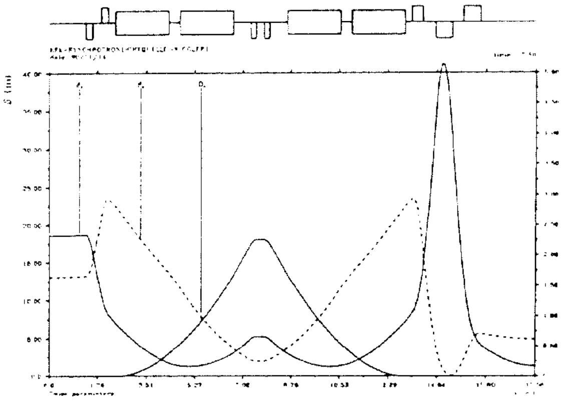

Fig. 4: Twiss functions and lattice designed for the implementation of two wigglers

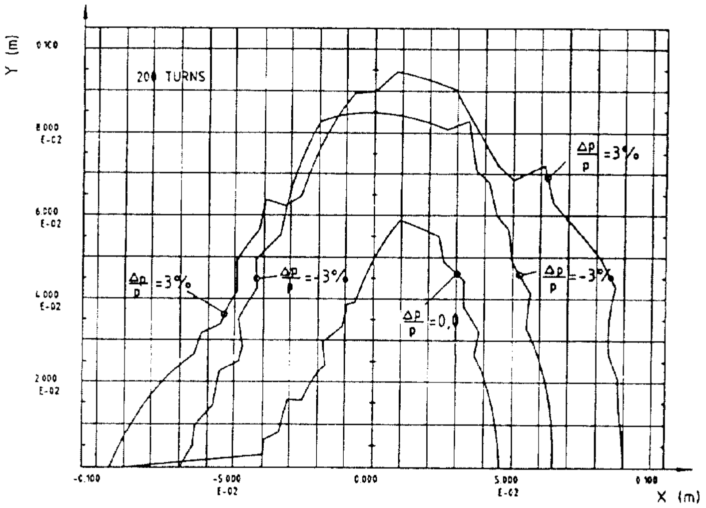

Fig. 5: The dynamic aperture of the KfK storage ring

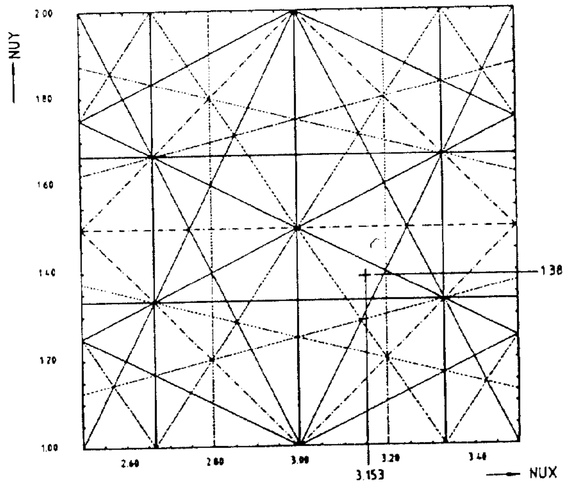

Fig. 6: The tuning diagram of the KfK storage ring