SC-Wavelength Shifter for Deep X-Ray Lithography at BESSY I

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1 INTRODUCTION

The progress in microstructure technology in Germany and especially the success of the LIGA-process ask for an encreased number of adequate exposure stations for lithography purposes on the short term timescale. While the planning and the construction of a dedicated source would take years, it is possible to provide exposure stations in a clean room environment, with much of the necessary infrastructure already exsisting, by introducing a superconducting wavelength shifter (WLS) in the existing $800 MeV$ electron storage ring BESSY. Using a commercially available $6T$ WLS, first deep X-ray lithography experiments could start after ≈ 18 months, [1].

2 MOTIVATION FOR DEEP X-RAY LITHOGRAPHY

The radiation produced by the dipole magnets of storage rings of the second generation, like BESSY I, with wavelengths around $1nm$, is well suited for most lithography purposes with structure hights of $0.2 - 5\mu m$. The production of deeper structures, as used in micromechanics where processing reaches down to $1mm$, requires harder radiation with wavelengths of $0.2 - 0.5nm$, Fig.1. Shorter wavelengths are either obtained by a higher energy, i.e. new facilities, or by inserting WLSs into the existing rings.

Calculations of the spectra of a $6T$ WLS in BESSY I show that the accessible depth for processing would increase by an order of magnitude, while the exposure time would be cut to less than half, only $30 - 60min$ for $1mm$. Furthermore, the WLS beamlines would end directly in the existing clean room lithography laboratory of the Fraunhofer-Institut für Mikrostrukturtechnik, which works on the development of techniques and instrumentation for X-ray lithography for over 10 years. Not only hard synchrotron radiation, but a well equipped and experienced working environment could be provided at BESSY.

3 TECHNICAL DATA

In the following we assume the WLS to be of the commercially available Daresbury type [2]. It consists of three superconducting dipoles, the central one with a peak field of $6T$, and two compensation dipoles of $1.3T$. Under regular conditions at BESSY, i.e. $800MeV and 500mA$, $2 \cdot 10^{12}$ photons per $s \cdot mrad$ will be emitted at a wavelength of $0.2nm$

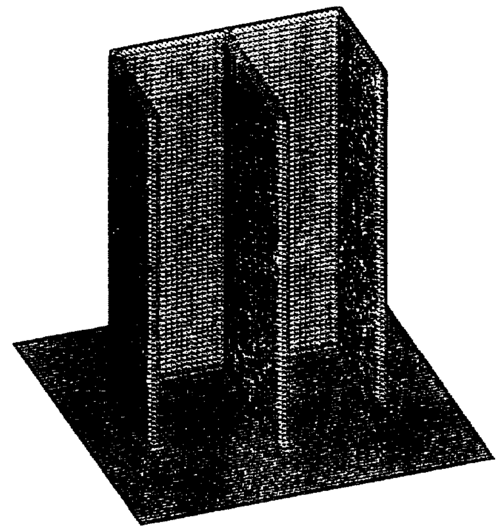

Figure 1: Calculation of a resist profile (300 μm high, wall thickness $10\mu m$), on the basis of the X-ray spectrum expected for the WLS in the BESSY storage ring, and PMMA resist.

and within a bandwidth of 0.1%. The critical wavelength is $\lambda_c = 0.49nm$, and the opening angle $\Theta_c = 0.64mrad$.

Due to mechanical reasons, the WLS will be located $300mm$ off center in the straight section between quadrant 1 and 2 of the ring. To generate the space for the $1156mm$ long device, the $62.5MHz$ cavity will be shifted closer to the quadrupoles, while the $500MHz$ cavity is moved to another straight, Fig. 2.

The necessary modifications of the ring would primarily take place in the regular maintenance weeks of the facility. Only about three weeks of additional shut down time distributed over 18 months are required to finish the installations.

4 WLS-OPTICS

The injection into the vertical plane and the asymmetric sextupole scheme of the BESSY storage ring make it difficult to insert a superconducting, vertically focussing WLS into the optics. It will be necessary to reduce the vertical β-function at the WLS, to reduce the betabeat, and to extend the existing sextupole scheme, to seek good non-linear behaviour. The new optics fullfills the following criteria:

- except for the reduced vertical β-function at the WLS the optics agrees as well as possible with the BESSY

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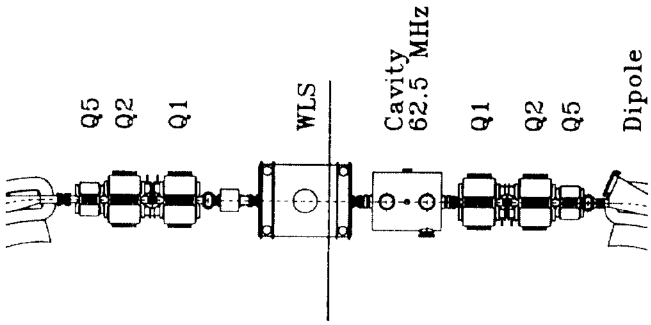

Figure 2: Modified straight section with the WLS, the additional quadrupole magnets, Q5, and the symmetry line.

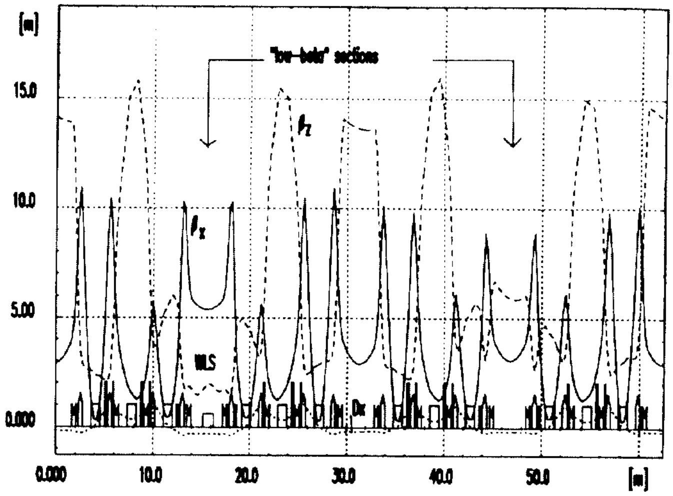

Figure 3: Linear lattice functions of the WLS-optics with the WLS and two "low-beta" sections.

standard optics V-METRO to maintain the experimental conditions for the other users and the high quality and reliability of the light source

- the hardware modifications of the storage ring are kept at a minimum
- it is still possible to run the V-METRO optics without hardware changes

The lattice modifications primarily consist of the installation of two pairs of new quadrupole magnets, one in the straight section of the WLS, and one opposite in the straight section of the crossed field undulator U2. The magnets will be placed at the location of sextupole magnets that are not powered in the V-METRO optics. The resulting quadrupole triplets are used to create two "low-beta" sections. They are powered in two pairs to allow local beat compensation introduced by the WLS. The second "low-beta" section improves the stability of the linear optics and its chromatic behaviour.

Chromaticity compensation with the existing sextupole families leads to poor dynamic apertures. New sextupole magnets will therefore be installed, one between each of the eight quadrupole doublets in the achromatic arcs. This configuration is a compromise between the size of the dynamic aperture and the amount of hardware changes in the ring, i.e. shut down time, needed. The magnets will be devided into two families, consisting of the four magnets in front and behind the central dipole, respectivly. The presented optics seeks good results using only one of the new sextupole families. The second family provides the flexibility to change to alternative optics.

4.1 COMPARISON WITH V-METRO

The linear model of the present V-METRO optics has been extracted from measured data. The agreement between measured and calculated β-functions is on average better than 5%.

For the WLS-optics, the working point and the β-functions in the straight sections and at the central dipole were adjusted to V-METRO. Only after the optics has been fixed, the WLS is moved to his final, asymmetric location. The resulting beat is negligible. Fig.3 shows the linear lattice functions.

Table 1: Main optic parameters.

	V-METRO	WLS-optics
superperiods	4	1
energy [MeV]	800	800
Q_x (working point)	5.5705	5.5728
Q_z	2.2769	2.2949
$\epsilon_0[10^{-9}\pi\cdot$ m $\cdot$ rad]	60.2	50.2
ξ_x (chromaticity)	-10.8	-11.0
ξ_z	-8.4	-7.6
α (mom. compaction)	.0169	.0178
β_x [m]: inj./WLS/U2	2.4	2.9/5.4/3.1
β_z	13.5	14.7/2.3/6.4
η_x [m] (dispersion)	-.19	-.17/-.29/-.17
σ_x (beamsize) [mm]	.62	.61/.94/.62
σ_z (K=1 %)	.09	.09/.04/.06
$\Sigma\, SF$ [m^{-2}]	4 $\cdot$ -7.7	4 $\cdot$ -6.7
$\Sigma\, SD$	4 $\cdot$ 4.5	4 $\cdot$ 5.0
$\Delta Q_x^{max} \pm 1\% \frac{\Delta p}{p}$	.052	.011
ΔQ_z^{max}	.048	.018
- A_x [mm] (aperture)	-10/-18/-16	-11/-12/-10
A_x (-1/0/1% $\frac{\Delta p}{p}$)	11/27/26	12/13/13
A_z	22/>40/>40	20/29/30

For the calculations of the non-linear effects the sextupoles of both optics have been tuned to compensate the calculated natural chromaticity to $\xi_x = \xi_z = +1$. All calculations have been performed with BETA [3], a modified version of BETA with an improved treatment of insertion devices [5] and RACETRACK [4].

In Table 1 the main parameters of both optics are listed. In most cases the agreement is better than 10%. The

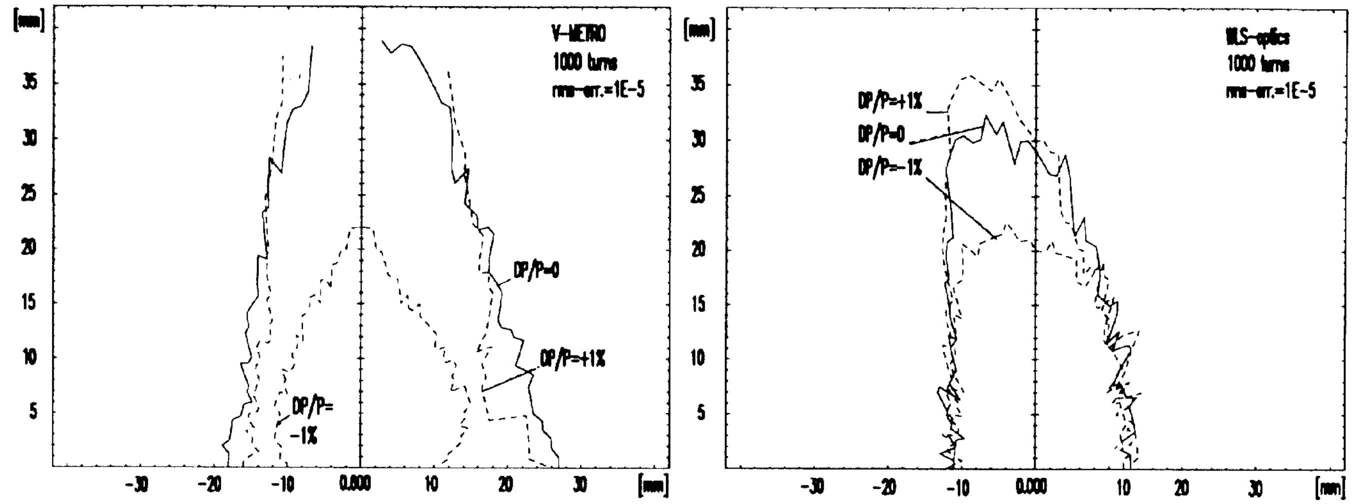

Figure 4: Dynamic apertures for V-METRO (left) and the WLS-optics (right) for three different momenta.

tuneshift with energy has been drastically reduced. The emittance is almost 20% smaller. In the dipoles next to the "low-beta" sections the vertical β-function increases by a factor of two. As the size of the vertical dispersion dominates the vertical beamsize, only minor changes of the actual spotsizes are expected. Dynamic apertures were calculated for 1000 stable turns and errors with a rms-value of 10^{-5} leading to typical closed orbit deviations of $\approx 1mm$. Fig.4 shows the dynamic apertures of both optics for the nominal energy and $\pm 1\%$ energy deviation.

The (measured) energy spread in BESSY is $\pm 1\%$, so only the smallest aperture is relevant for V-METRO in Fig.4. The calculated horizontal aperture strongly depends on the rms-error chosen, and collapses to $\approx \pm 10mm$ for rms values of 10^{-4}. Both is in good agreement with the measured horizontal dynamic aperture of $\pm 10mm$. Due to the broken symmetry in the linear WLS-optics, the horizontal aperture of this optics is stable for larger rms-values and is thus considered sufficiently large. The vertical aperture is in both cases limited by the $20mm$ dipole gap and the injection septum.

5 CONCLUSION

It has been shown that it is possible to modify the lattice and the optics of the BESSY I storage ring, to provide for the possibility of inserting a $6T$ superconducting WLS in one of its straight sections. The resulting hard radiation with wavelengths of $0.2nm$ is perfectly suitable for deep X-ray lithography purposes, and would allow processing down to a depth of $1mm$. The experimental conditions at the other beamlines would be preserved in most cases and most global machine parameters vary less than 10%, thus insuring the reliable high performance of the facility.

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7 REFERENCES

[1] K. Bürkmann, H. Huber, E. Jaeschke, D. Krämer, B. Kuske, P. Kuske, M. Martin, H. Oertel, M. Scheer, L. Schulz, G. Ulm, E. Weihreter, G. Wüstefeld, Ein Wellenlängenschieber für BESSY I, Technischer Bericht 168/92.

[2] K. Smith, Oxford Instruments, Scientific Research Devision, priv. communication 1992.

[3] L. Farvacque, J.L. Laclare, A. Ropert, ESRF-SR/LAT-88-08, February 1989, Beta Users' Guide.

[4] A. Wrulich, DESY 84-026, March 1984, Racetrack a Computer Code for the Simulation of Nonlinear Particle Motion in Accelerators.

[5] M. Scheer, G. Wüstefeld, Effects of a Superconducting Wavelength Shifter on the Storage Ring BESSY II, Part I: Canonical Tracking Calculations, Technischer Bericht 169/92.