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To cite this article: C Sánchez-Hanke et al 2013 J. Phys.: Conf. Ser. 425 152017

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High coherent flux at the NSLS-II coherent soft x-ray beamline

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Abstract. The optical design of the coherent soft x-ray (CSX) and fast polarization switching beamline at NSLS-II has been optimized to deliver photon flux in the range of \(10^{12} - 10^{13}\) ph/s in the energy range from 200 to 2000 eV. Two identical APPLE-II undulators will be operated in two different modes: canted and phased. In the canted mode, one beam will be directed to the coherence branch and the other to the fast polarization switching branch. In the phased mode, the two undulators will be operated as a single device to deliver the highest coherence flux to the coherence branch. The monochromator for the coherence branch is a focusing variable line spacing plane grating monochromator designed to deliver a moderate resolving power (2000 to 3000). The horizontal focusing onto the exit slit will be performed with a cylindrical bendable mirror located downstream of the monochromator and having similar demagnification as the monochromator.

1. Introduction

The main considerations on the optical design of the coherent branch were to minimize the number of optical components and reduce the optical aberrations such as to obtain the highest possible coherent flux for photon hungry experiments with low to moderate energy resolution. This has been achieved with the use of a focusing variable line spacing plane grating monochromator [1] and a bendable cylindrical mirror that create an image of the source at the exit slit with similar demagnification. This optical design allows one to compensate for the different source positions when using either one or two undulators. Furthermore, it allows to move the focus to different distances. This branch will serve experiments dedicated to coherent diffraction contrast microscopy, scanning diffraction microscopy (ptychography), and photon correlated spectroscopy with an emphasis on the study of strongly correlated materials and magnetic systems. The capability of the beamline in positioning the stigmatic focus at different distances allows for flexibility in the illumination scheme used in the experimental station. The exit slit can be placed one meter upstream of the sample, thereby allowing for the illumination of a large diameter zone plate for imaging with a small spot, or the exit slit can be placed near the sample allowing for illumination from a pinhole thus covering a larger field of view. This ability to drastically change the coherent intensity on the sample will allow users to tune the beamline to the specific needs of their experiment.

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2. Source
Two 1.9 m, 49.2 mm period, APPLE -II [2] undulators will serve as the source for the two branches of the CSX beamline. The devices (already being fabricated) will be installed in one of the short straight sections of the NSLS-II storage ring. A canting/phasing magnet system will allow to operate the insertion devices (ID) to provide either canted beams by 0.16 mrad or phased. In the canting mode, the IDs will either deliver beams of opposite polarization to the fast polarization branch [3] or independently controlled beams to each one the branches. In the phased mode, the magnet in between the two devices will allow to operate the devices to deliver maximum coherent flux to the coherence branch [4].

In the phased mode of operation, the position of the beam waist is in between the two devices whereas when using a single undulator the vertical waist is close to the center of the ID and the horizontal waist is closer to the center of the straight section. The difference in horizontal and vertical waists positions, which also varies with changing photon energy, was simulated using the SRW code [5].

The parameters of the electron source used in the calculations and ray tracings are: Electron energy: 3 GeV; current: 0.5 A; RMS source sizes $\sigma_{x,y} : 28, 2.6 \mu m$; RMS divergences $\sigma'_{x,y} : 20, 3 \mu rad$. The minimum photon energies to be delivered in the different polarization modes are: linear horizontal 160 eV, circular 220 eV, linear vertical 260 eV, and linear $45^\circ$: 380 eV. The cutoff for the first harmonic is approximately 1.7 keV.

3. Optical Design
Since the coherence branch will use either one or both of the insertion devices the optical design needs to compensate for the different source positions. This can be achieved with a focusing variable line spacing plane grating monochromator (FVLSGM) [1] which can correct for the position of the vertical source waist and a bendable elliptical cylinder to correct for the position of the horizontal source waist. Actually, a bendable cylinder is appropriate due to relatively low beam divergence and moderate demagnification.

A schematic drawing of the beamline optical layout is shown in Fig. 1. The distance from the source, the angles of incidence, the deflection of the optical elements and their demagnification are listed in table 1.

The first optical element is a plane mirror located outside the shield wall which deflects the beam horizontally by $2.5^\circ$. Its main function is to absorb the high photon energies emitted by
Table 1. Optical elements of the coherent branch

| Optical element          | Distance from straight center (m) | Incidence angle (degrees) | Deflection plane | Demagnification Hor./Ver. |
|--------------------------|----------------------------------|---------------------------|-----------------|--------------------------|
| Plane (cooled)           | 29.0                             | 88.75                     | Horizontal      |                          |
| Plane (cooled)           | 40.2 - 40.4                      | 87.0 - 89.0               | Vertical        |                          |
| LEG: Grating (cooled)    | 40.5                             | 87.2 - 89.1               | Vertical        | /5.0 - 3.9               |
| HEG: Grating (cooled)    | 40.5                             | 87.2 - 89.1               | Vertical        | /5.0 - 3.9               |
| Cylindrical (Bendable)   | 42.5                             | 88.75                     | Horizontal      | 4.9 - 3.8/               |
| Sample                   | 53.5 - 57.5                      |                           |                 |                          |

The second optical element is the plane mirror in the monochromator which deflects the beam downwards (in the dispersion plane) towards the grating. This mirror needs to be rotated and translated in order to provide the grating with the correct angle of incidence, $\alpha$, that will keep the beam focused at the exit slit at all wavelengths. The rotation and translation are actually incorporated in a simple rotation around an axis not on the mirror surface [6]. Setting the angle of incidence on this mirror to $\gamma = 0.5(\alpha - \beta)$, where $\beta$ is the diffraction angle (negative), ensures the selected photon energy stays horizontal after the monochromator.

The last element of the beamline is a bendable cylinder deflecting the beam horizontally by 2.5° and focusing it horizontally at the exit slit. We have chosen a bendable mirror to correct for the source position change and the heat load induced slope error on the first optical element as described in Ref. [3].

We note that the combination of the FVLSPGM and the bendable cylinder can produce a focused beam over the range $\pm 2\text{m}$ along the beam direction as verified by analytical and ray tracing calculations.

4. Expected Performance

The large distance between the source and the grating and the fact that the source is almost diffraction limited along the vertical direction means that a modest resolving power can only be achieved with a low line density grating and using a low $c = \cos \beta / \cos \alpha$ factor. To achieve the required resolving power of $\approx 3000$ we chose two gratings with central line densities of 70 l/mm (LEG) and 100 l/mm (MEG) operating with $c = 1.2$. As mentioned above, the source will be either one or two IDs. The fact that the beamline does not have an entrance slit means that the resolving power will depend on the source in use.

The monochromator “resolving power” (RP) was calculated from the vector sum of all the relevant contributions to the resolution: source size, aberrations, slope errors, and exit slit. The exit slit width was set such that its contribution to the resolution is the same as that due to the source size. The zeroing of the coma and spherical aberrations at 500 eV (1000 eV) for the LEG (HEG) with the quadratic and cubic term of the grating line density makes their contribution to the resolution negligible as compared to that of the source size. Meridional RMS slope errors of 0.1 $\mu\text{rad}$ on the grating, 0.2 $\mu\text{rad}$ on the plane mirrors, and 0.5 $\mu\text{rad}$ in the elliptical cylinder were assumed in the calculations. Their combined contribution to the resolution is lower than that of the source at low photon energies but larger that of the source at high photon energies.
The total resolving power (RP) calculated for one and two IDs with the LEG and the HEG are shown in Fig. 2. As expected, the RP of the two IDs is worse than that of a single ID since the coherent source size is approximately proportional to the square root of the device length.

Figure 2. ‘Resolving Power’ with the two gratings and with one and two insertion devices. Dotted lines: Using one ID; Solid Lines: Using both IDs; Red: HEG; Black: LEG

Figure 3. Coherent flux through the exit slit with the two gratings and with one and two insertion devices. Dotted lines: Using one ID; Solid Lines: Using both IDs; Red: HEG; Black: LEG

The coherent flux transmitted by the beamline (F) for each one of the RP curves shown in Fig. 3 was calculated using $F = \epsilon B \lambda^2 / 4$. ($\epsilon$) includes the mirrors reflectivities, the gratings efficiencies calculated using the exact electromagnetic theory [7] assuming trapezoidal grooves and Au coating on all elements and the bandwidth correction due to the exit slit resolution. $B$ is the source brightness (calculated using the spectra code) [8] and $\lambda$ is the wavelength. We note in passing that the reduction in coherent flux due to the meridional slope errors on the plane mirror inside the monochromator chamber and the grating are taken into account through the “resolving power”.

All mirrors and gratings, monochromator and mirror chambers are in the procurement phase. Beamline commissioning will start in summer of 2014.

5. Acknowledgment
Support of this work at the National Synchrotron Light Source and NSLS-II, Brookhaven National Laboratory, was provided by the U.S. Department of Energy, Office of Science, Office of Basic Energy Sciences, under Contract No.DE-AC02-98CH10886.

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