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New beamline optics for the effective use of a wiggler beam

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A hard X-ray beamline, BL13A, has been constructed for precision diffraction experiments conducted downstream of the multipole wiggler MPW#13 at the Photon Factory. The BL13A line can be used along with the main beamline, BL13B, which accepts the central 4 mrad of the 5 mrad horizontal fan. BL13A uses the remaining horizontal off-axis beam. The beam is diffracted by a double-crystal monochromator which uses asymmetric (422) diffraction with a horizontal diffraction vector. A monochromatic beam with 33.5 keV photon energy is directed to a precision goniometer. Good beam stability and high intensity were obtained.

Keywords: hard X-rays; wigglers; precision goniometry; horizontal diffraction; new beamline optics.

1. Introduction

It was desirable to extend the usable spectral range to high X-ray energies because the availability of high-intensity sources in the high X-ray range is very limited. X-ray diffraction experiments with a photon energy higher than 22 keV (Ag $K\alpha$) are not easy to carry out even with X-ray tubes. Peak brilliance occurs around 4 keV at the normal bending magnets of the Photon factory. The brilliance at 20 keV is about 1/20 of the peak value. The multipole wiggler MPW#13 (Sasaki *et al.*, 1989) has 27 poles, the maximum magnetic field is 1.5 T and the brilliance at a photon energy of 30 keV is equal to the peak brilliance of a normal bending magnet.

The beamline, which is designated BL13A, was intended to be used for precision diffraction experiments in the hard X-ray region. A unique feature of this beamline is the use of a horizontal double-crystal monochromator to gather otherwise abandoned beams. The beamline can be operated simultaneously with the main line. Vertical diffraction optics are generally employed at normal bending and horizontal wiggler beamlines in order to avoid intensity loss by polarization. The loss is not serious for BL13A because the glancing angle for hard X-rays is small. Here, we briefly describe the geometrical layout, alignment procedure and performance of this beamline.

2. Beamline layout and optical components

A schematic layout of the beamline is shown in Fig. 1. Another branch beamline of BL13 for soft X-ray experiments is not shown in this figure. A fixed-exit double-crystal monochromator (branch beamline monochromator) was installed upstream of the main beamline. The centres of the main and branch beamline pipes are separated by 300 mm. The monochromator chamber is divided into two parts (Fig. 2). The first crystal is in a clean and high-vacuum chamber connected windowless to the main beamline, which is kept at a high vacuum of 10^{-6} to 10^{-7} Pa for low-energy X-ray experiments. The second crystal is in a normal vacuum chamber. A long beryllium window (666 mm long, 26 mm high and 0.5 mm thick) separates the first and second crystal chambers and keeps the main beamline clean. In the limited space of the beamline, the overall length of the monochromator chamber is 1500 mm and the minimum Bragg angle is 8°. The main axis of the first crystal is 20.15 m from the centre of MPW#13.

BL13A is usually used with monochromatic X-rays. Use of BL13A for continuous energy scans was not intended, but is possible in a narrow energy range. Horizontal or vertical diffraction can be used at the sample after the beam has been separated from the main line.

3. Monochromator

The monochromator uses two asymmetrically cut Si(422) crystals [70 mm (H) × 40 mm (V)] in non-dispersive geometry. The Bragg angle of lower-order net planes is too small to diffract hard X-rays. The (422) net plane makes an angle of 13° with the surface of the crystal. A glancing incidence is used in the first crystal to decrease the heat load and protrusion of the crystal into the main beam. A glancing exit is used in the second crystal to reduce the beam size. A wider beam size is produced by a longer crystal and larger take-off angle in the second crystal.

The photon energy is spanned by rotation of the first crystal, while the second crystal rotates and translates. These movements are made by a drive mechanism that is coupled to stepper motors. In addition to the main drive, three other *in situ* adjustments of the first crystal are possible: using an in-vacuum stepper motor for x-translation and two hinged tilting tables driven by in-vacuum DC motors for adjusting ‘pitch’ (tilting the net plane normal in the vertical plane) and ‘roll’ (rotation around the net plane normal). Flexure hinge mechanisms were adopted for the sake of stability and vacuum compatibility, although the range of adjustment is narrow. The pitch and roll of the second crystal can be adjusted in the same manner.

The x-translation stage is used to move the first crystal into the wiggler beam to diffract a 2 to 3 mrad horizontal off-axis beam after the main shutter of BL13 is opened. The translation is mechanically stopped at a position 20 mm from the centre of the beam pipe to prevent crystal overrun into the main beam.

It was necessary to install a correction device to eliminate drift of the diffraction angle, because heating of the first crystal in the white beam makes the system slightly dispersive due to differing thermal expansion of the two crystals. To compensate for this

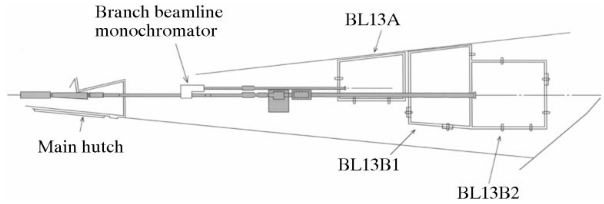

Figure 1
Layout of BL13 (top view). The wiggler is on the left side of the figure.

Table 1
Diffraction angles.

Crystal angular position	
+ Position (8 data)	358.1448 ± 0.0008°
− Position (8 data)	9.3273 ± 0.0004°
Bragg angle	59.5913 ± 0.0009°

error, a piezoelectric transducer (PZT) is incorporated in the first-crystal mount assembly so that the Bragg angle can be adjusted over a range of 10 mrad with 10 nrad resolution.

The first crystal is pressed against a water-cooled copper block. The temperature of the first crystal is measured by a platinum resistance thermometer attached to the lower part of the incidence surface.

4. Adjustment of the monochromator

Mirror surfaces were prepared on the crystals for optical adjustment of the net plane normals. The surface of the first crystal was mirror polished without causing strain field in the crystal. A small mirror was glued onto the top surface of the second crystal. The crystals were arranged in a non-dispersive position at an X-ray tube generator. The net plane normal of the first crystal was adjusted to be horizontal, then the second-crystal net plane was adjusted parallel to that of the first crystal. The angle between the gravitational direction and normal of each mirror was measured with an autocollimator. The base of each crystal was ground flat in a direction such that the roll was optimum when the crystal was placed on a horizontal plane.

The crystals were attached to the goniometer heads of the monochromator and the normals to the mirrors were optically adjusted at proper angles to the vertical direction. The reflections of the crystals were easily detected by fluorescent screens set in the vacuum chamber of the second crystal. After reflection was detected, the pitch and roll of the crystals were changed slightly to direct the monochromatic beam into the hutch 12 m downstream of the second crystal.

5. Flux

The angle of the first crystal was set close to the minimum Bragg angle. X-rays with photon energies of 16.7 and 33.5 keV were selected by the monochromator at a Bragg angle of 19.5°. The beam size in the hutch was about 3 mm (H) × 7 mm (V). Flux measurements were made using a silicon pin photodiode (Hamamatsu Photonics, S3590-06) with a wafer thickness of 500 μm and zero bias voltage. A photocurrent of 12 nA was measured with the photodiode placed 33 m from the source, with a 2 mm-diameter slit in front, and a ring current of 350 mA at 2.5 GeV. A flux of 7×10^8 photons s^{-1} cm^{-2} at 33.5 keV was estimated from the calibration data of the photodiode (Ban *et al.*, 1994) and from the calculated spectra of the wiggler (Sasaki *et al.*, 1989), where about one-third of the total photocurrent was attributed to the 33.5 keV photons.

The beamline was designed to receive a 2 to 3 mrad horizontal off-axis beam from the wiggler. The centre of the wiggler beam, however, was found recently to be about 10 mrad off-axis from the centre line of the main beam pipe. The beam pipe seems to have been constructed along a wrong line. When the beam pipe is placed in the optimum position, the flux will be at least ten times higher than the above-mentioned flux.

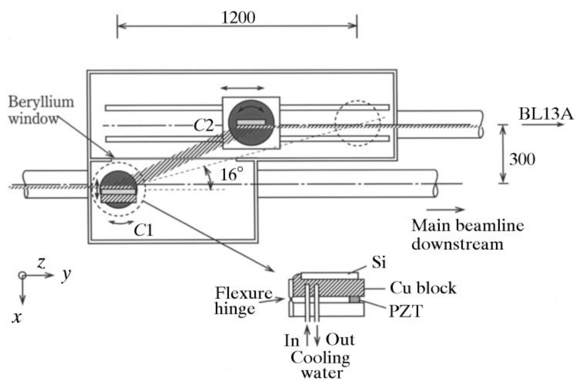

Figure 2
Top view of the branch beamline monochromator. Dimensions are in mm.

6. Beam stability

Shortly after the first crystal was brought into the beam, the diffracted intensity changed rapidly due to the temperature rise of the first crystal and crystal holder caused by strong wiggler radiation. On the other hand, the second crystal remained at room temperature. The intensity was oscillating slightly because of movement in the first crystal caused by the flow of the cooling water. When the flow of water was decreased, the oscillation disappeared but the crystal temperature increased steeply. After a few hours, the temperature rise stopped at about 353 K, the intensity drift decreased and the intensity could be stabilized by the correction device.

Photocurrent from the pin-photodiode, which measures X-ray intensity in the hutch, was amplified and fed to the PZT to correct the Bragg angle of the first crystal of the monochromator. The second crystal was set at an angular position and the slit placed in front of the pin photodiode fixed the diffracted wavelength from the monochromator, because the lattice spacing and Bragg angle of the second crystal were constant.

An Si(220) crystal was mounted on a precision goniometer in a symmetric Laue setting and the diffraction angles were measured in the (+,−,+) and (+,−,−) positions (Fig. 3). The angles corresponding to the peak reflection intensities are shown in Table 1. The small standard deviation of the angle reflected the stability of the beam at the sample and mechanical stability of the goniometers.

The wavelength of the second harmonics was 0.37417 ± 0.00006 Å obtained from the Bragg angle, and the lattice spacing of silicon $d(220)$ = 1.920160 Å at 296.35 K (Nakayama & Fujimoto, 1997). Wavelength uncertainties mainly came from the standard deviation of peak angle measurements.

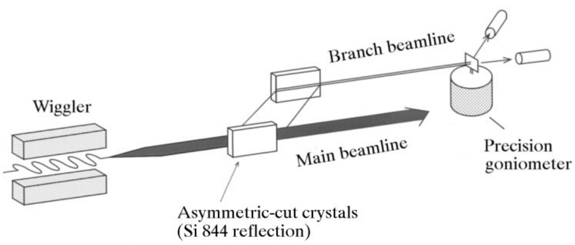

Figure 3
Arrangement for wavelength calibration.

The horizontal separation of a wiggler beam will provide a hard X-ray station for studies such as topography using extremely high-order reflection, precision measurements of the rocking curve in a low absorption case, and structure analysis.

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