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Asymmetric Fraunhofer Diffraction from Roller-Blade Slits

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X-ray diffraction experiments under coherent conditions have been made possible by the development of new sources of synchrotron radiation, but make tough demands on the experimental apparatus. Here we describe the design and initial testing of a precision aperture that uses polished molybdenum rods as the slit blades. The device has an inherent asymmetry which is accurately accounted for by a simple modification to the Fraunhofer diffraction function.

Keywords: coherent X-ray diffraction; precision apertures; slit design.

1. Introduction

The recent growth in the nascent field of coherent X-ray diffraction has been spurred by the coming of high brilliance third-generation synchrotron radiation sources, such as the ESRF and APS. There are interesting crystallographic applications of coherent X-ray diffraction, illustrated by Robinson *et al.* (1995), which need to be explored further. New technology for carrying out experiments will be needed in addition to developments of the sources themselves. Examples of these are small-pixel area detectors, small sphere-of-confusion diffractometers, precision sample positioners and precision slits. Here we report our progress towards the development of the last item, a precision slit system.

2. Slit systems

Slits are required to cut the beam incident on the sample down to a size that is comparable with the inherent lateral coherence of the beam, which is itself determined primarily by the size of the electron beam in the storage ring source, σ. An experiment positioned at a distance D away from this source receives radiation with a lateral coherence length, ξ, where

$$\xi = \lambda D/\sigma \qquad (1)$$

and λ is the X-ray wavelength. An ideal coherent X-ray diffraction experiment must then use an aperture smaller than ξ. Typical values for σ are in the range 50–500 µm, giving ξ in the range 2–20 µm.

To define a beam of this size precisely requires two blades of dense material with sufficient thickness to block the beam. Local fluctuations in the form of roughness (on the scale of ξ) are not tolerated within the beam width, which therefore demands a highly polished finish. A common way to do this is to use blocks of tungsten or tantalum, but this has two potential problems: spurious beams reflected from the flat face, and grading of the beam edge if the face of the block is not exactly parallel with the beam. To avoid roughness, a clever trick is to use a cleavage plane of a crystal such as GaAs, which has been recently demonstrated by Pindak (1996).

Following the ideas of Johnson (1995) and Hauserman (1995), we favor the alternative of using a roller blade of sufficient diameter that the penetration is limited to less than 1 µm for typical X-ray energies. For dense materials

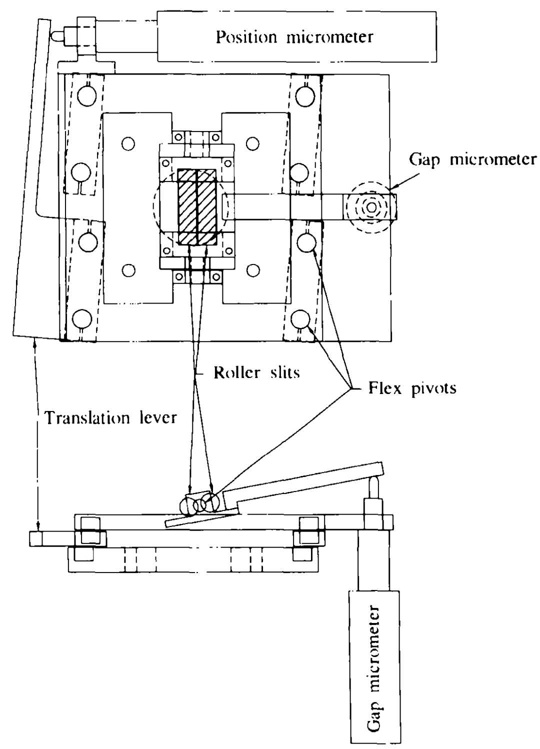

Figure 1
Design of a mechanism for rotating two roller-blade slits to define a precise aperture, and positioning of that aperture. All movements are sustained by flex-pivots. Two such mechanisms are stacked to produce a pinhole. Above is a front view showing the levered translation motion; below is a top view showing the rotation mechanism.

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like tungsten and molybdenum, this can be achieved with a rod of diameter 10 mm. The cylindrical geometry of the roller is also favorable for polishing of the surface, which we carried out with 0.05 μm alumina paste.

The next consideration is the positioning system. Commercial motorized micrometers (of standard quality) have a resolution of ~1 μm, which is not quite sufficient for the task. The movements must be free from friction and smooth at this level too, which is difficult to achieve with ball-bearing slides. We use a levered flex-pivot design which is shown in detail in Fig. 1. One micrometer drives the position of the slit *via* a 4:1 lever arm; the second changes the effective gap between the two rollers by rotating the pair as a rigid unit. The sensitivity of the setting is controlled by the spacer between the roller blades, which we made ~200 μm thick.

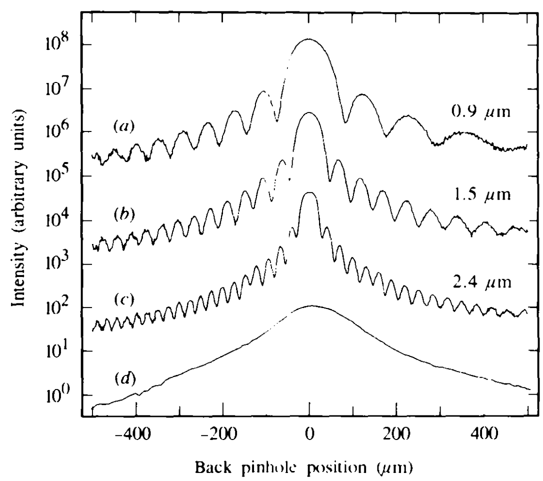

Figure 2
Fraunhofer diffraction from a roller-blade slit measured at the X16C beamline of NSLS using 8 keV X-rays. The measurements were made by scanning a small second slit across the diffracted beam at a distance of D = 0.914 m. The traces are displaced apart by two decades for clarity. The front slit separations were (*a*) d = 0.9 μm, (*b*) d = 1.5 μm, and (*c*) d = 2.4 μm. Trace (*d*) was obtained with ground tungsten rods instead of polished molybdenum, also with a front slit of d = 2.4 μm.

3. Experimental

We tested the design with synchrotron radiation from the X16C and X25 beamlines at NSLS. A useful demonstration of beam coherence in coherent X-ray diffraction is the observation of the interference fringes obtained by Fraunhofer diffraction, the diffraction due to the finite size of the slit itself seen from a large distance away. On X16C we used a beam of 8 keV defined by two Si(111) monochromator crystals. At X25 we used W/B multilayers with a d spacing of 25 Å to define a beam centered at 7 keV with a 2% bandwidth. The effects of the bandwidth are unimportant in Fraunhofer diffraction. Viewed as a function of position, y, in a plane a distance D away from the slit, the observed intensity is expected to follow the form of a slit function,

$$I(y) \propto [\sin(2\pi y/\eta)/(y/\eta)]^2, \qquad (2)$$

where the fringe spacing, $\eta/2$, is given as a function of the slit separation, d, by an analogous expression to (1),

$$\eta = \lambda D/d. \qquad (3)$$

4. Results and discussion

Typical results are shown in Figs. 2 and 3. The fact that many fringes of Fraunhofer diffraction are clearly distinguished indicates that the slits are well defined. More than 25 fringes on each side of the central maximum can be seen in the polychromatic X25 data (Fig. 3); the reduced contrast at the extremes can be partly attributed to the spread of wavelengths in the beam. Another contribution is the necessarily soft edges to the beam that are generated by penetration of the beam into the rollers. The effect of polishing is clearly seen in Fig. 2(*d*), which was obtained

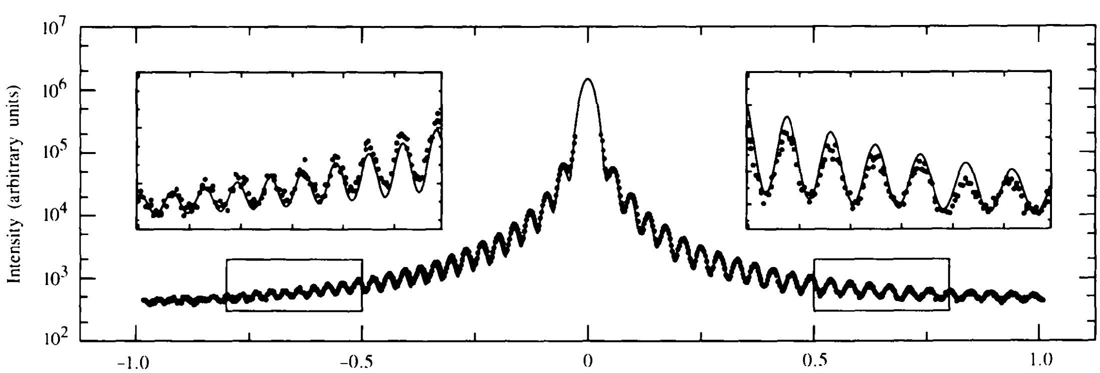

Figure 3
Fraunhofer diffraction from a roller-blade slit measured at the X25 beamline of NSLS using 7 keV X-rays. A 24 μm pinhole with position y was scanned across the diffracted beam at a distance of D = 1.35 m. Data points in the centre, where the detector saturated, have been omitted. The fit curve is the Fraunhofer diffraction function of equation (2) with a linearly varying slit size, $\eta(y) = \eta_0 + \gamma y$, with η_0 = 3.2 μm and $\gamma = -3.9 \times 10^{-4}$.

with centerless-ground rods of tungsten, instead of polished molybdenum. Here the fringes are not distinguishable at all. The finish of these rods was not noticeably poor, and is probably better than commercially available slits. Our result explains why Fraunhofer diffraction from inadequately polished slits or laser-burned (jagged) pinholes is often seen to fade away faster than expected (Grübel *et al.*, 1995).

The data as a function of the entrance-slit setting are good enough for a quantitative comparison with theory. However, there is a striking discrepancy in all these data with the functional form of equation (2): the asymmetry, which becomes more pronounced for the narrowest slit settings. The explanation of this effect is the parallax arising from the two blades no longer lying in a single plane once the assembly is rotated. In effect, the apparent slit size that gives rise to the Fraunhofer diffraction on one side of the pattern (positive y) is significantly different from the apparent slit size on the other side (negative y). It is possible to show that the rotated roller geometry indeed leads to a closely linear variation of the effective slit size, so we can model this effect very simply by taking η in equation (2) to be a linear function of position y.

A fit to the data of equation (2), with $\eta = \eta_0 + \gamma y$, is superimposed in Fig. 3. The only parameters of this fit were a scale factor, a background (of 330 counts), and a slit width of 3.2 µm in the center ($y = 0$) varying linearly from 3.6 µm on the left side of the figure ($y = -1$ mm) to 2.8 µm on the right side ($y = +1$ mm). The fit was smeared by convolution with a box function of width 20 µm representing the resolution of the back pinhole. The excellent agreement obtained testifies that the description is adequate and that the slits are acting ideally. Note that not only is the variation of the oscillation period explained by the model, but the asymmetry in the amplitude as well.

5. Conclusions

We have shown by demonstration of Fraunhofer diffraction at a quantitative level that sharp edges of an X-ray beam can be defined by an appropriately designed slit. The asymmetry in the resulting patterns can be attributed to parallax.

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