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A SIMPLE SAGITTAL FOCUSING CRYSTAL WHICH UTILIZES A BIMETALLIC STRIP*

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G. S. Knapp, M. Ramanathan, H. L. Nian+, A. T. Macrander+, and D. M. Mills+
Materials Science Division
+Advanced Photon Source
Argonne National Laboratory
Argonne, IL 60439

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G. S. Knapp and M. Ramanathan
Material Science Division
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ABSTRACT

A sagittal focusing monochromator which utilizes a bimetallic strip as its active focusing member has been designed and has undergone preliminary testing. The crystal bender is very easy to use as only setting the temperature of the bimetallic strip is necessary to adjust the focus. The mechanism utilizes bending rods mounted on live centers which prevent twisting of the crystal. A finite element analysis has been done on a new ribbed crystal which, based on the analysis, should have very small aberrations.

INTRODUCTION

The sagittal focusing of synchrotron x-rays[1] is an excellent method of providing horizontal focusing on bending magnet beam lines. The recently commissioned NSLS beam line, *X6B*, was initially equipped with a pair of flat monochromator crystals in a compact mounting arrangement. While it was clear it would be very useful to modify this monochromator assembly to allow sagittal focusing there was little room to install conventional fine positioning devices normally used to provide the bending of the crystal. We therefore have devised a bending mechanism which is very simple and compact and employs a simple bimetallic strip to provide the bending. The device is quite easy to use as only one active adjustment is necessary.

There have been many beamlines which have used the sagittal technique[2] since Sparks *et al* [1] first described the technique. Many different bending mechanisms have been employed, some of which require several adjustment to keep the beam in focus. We wanted a bender which was simple to use, was compact, and provided focusing of the x-rays over a wide range of energies. The use of a bimetallic strip allows us to satisfy the above requirements. By changing the temperature from 30 to 120 ^{o}C we can change the radius of curvature from infinite of one meter. Since it is easy to control the temperature to a small fraction of a degree, it is easy to control this radius. By mounting the strip in its center and attaching the bending couple to each end, there is no change in beam direction as the crystal bends.

As Sparks *et al* [1] has shown, it is extremely important that the crystal be very flat in the direction of the beam. Any bending or twisting which produces angle changes over the cross section of the beam which are more than a small fraction of Darwin width causes a great loss of flux. They have shown[1] that it is necessary to use ribbed crystals in order to avoid anticlastic bending. It is also necessary to avoid twisting of the crystal. This can be done in a vary of ways, but perhaps the simplest is to mount the benders on live centers as discussed below.

DESIGN OF THE BENDER AND CRYSTAL

Figure 1a shows an end view of the sagittal bending assembly. The center mounting block and the bending coupling mechanisms are insulated from the bimetallic strip by thin pads of Teflon. The strip is heating by wrapping Teflon coated heater wire around the strip. Only about seven watts of power is required to heat the strip to its maximum temperature. The bimetallic strip was manufactured by Chase Precision Metals Inc.(3) and we used Chase type 6300. In their literature(3) they show how to calculate the force and deflection which can be provided by a given bimetallic strip. The thicker the strip the more force it can provide but the amount it will bend will decrease. We calculated that a strip 25 *mm* wide, 75 *mm* long and 1.4 *mm* thick would provide the force and deflection required for our purposes. In the design of the *X6B* monochromator the beam moves across the face of the crystal as the energy is changed so the second crystal must be quite long, at least 100 *mm*. A top view of the crystal bender is shown in figure 1b. The bending rods are only 25 *mm* long because it was impractical to get longer bending rods sufficiently straight as to not bend the crystal in the long direction. We are relying on the stiffening ribs to insure the crystal bends cylindrically.

Figure 1 depicts the live center mechanisms. Three of the bending rods are mounted on live center rods and are free to pivot and the fourth is fixed to establish a plane. The live center mechanism allows the three other rods to rotate so as to be parallel to the fixed rod thereby allowing no twisting to occur. The adjustment and locking screws allow adjustment of the vertical height of the top rods.

The first ribbed crystal we tried was mistakenly made very thin as it was necessary to heavily etch the crystal to remove the damage caused by grinding and polishing. The crystal was only 0.30 *mm* thick and its ribs were both thinner and shorter than necessary to provide enough stiffness. Nevertheless, quite good results were obtained from this crystal. Presently we are in the process of making a better crystal based on the results of a finite element analysis.

EXPERIMENTAL RESULTS

In the first experiment we tested the focal properties of the thin crystal as a function of temperature. Using radiation sensitive paper we looked at the size of the image at the sample position as a function of temperature of the bimetallic strip. As the crystal is bent the horizontal length of the image decreases. The experiment was done at an energy of 11.5 *keV*. We were focusing 1.5 *mrad* of flux so at a source to sample distance of 24 *m* the unfocused image was 36 *mm*. At about 62 ^oC the beam was focused and the smallest spot was about 1.5 *mm* in width. From

$$R = \frac{2F_1F_2}{F_1 + F_2} \sin\theta \qquad \text{... (1)}$$

where F_1 is source to crystal distance, F_2 is crystal to sample distance (10 *m* and 14 *m* respectively for beamline *X6B*), the radius *R* for the *Si* <111> crystal is calculated to be 2.01 *m* at 11.5 *keV*. In figure 2 we show the image length as a function of temperature. As the temperature increases the length decreases until 62 ^oC after which the length increases. The image has reversed so we plot this data as a negative length. In the next series of experiments the crystal was held in focus and the solid angle of the flux falling on the crystal was increased by use of a series of slits which were located before the crystal. We focused from 0.5 *mrad* to 3 *mrad* and the results are shown in figure 3. If the focal properties were perfect, the flux should have increased by a factor of six. As can be seen the flux only increased by a factor of 3.3. While these results are encouraging it is clear that there is scope for improvement. We are in the process of developing a better crystal the design of which will be discussed below.

DESIGN OF BETTER CRYSTAL USING FINITE ELEMENT ANALYSIS

The type of bender being used is designed to produce a cylindrical bend with the curvature perpendicular to the scattering plane direction. A perfect cylindrical bend will produce some aberrations and also some errors in the angle of the second crystal relative to the first crystal in the Bragg direction which will produce some loss of intensity. Sparks, Borie and Hasting[4] showed that there is no angle error if $F_1=3F_2$. Heald[5] showed this error, $\Delta\theta$, is given by

$$\Delta\theta = \frac{\omega_h^2 F_1}{R} - \frac{\omega_h^2 F_1^2 \sin\theta}{2R^2} \qquad \text{... (2)}$$

where ω_h is the horizontal divergence of the ray from the central axis. At the ratio of F_1 to F_2 at X6B, $\Delta\theta$ is about 1/5 of the Darwin width at 20 *keV*, if ω_h is less than 1.5 *mrad*. Therefore there will be only a small decrease in intensity due to the design of *X6B* if we only focus 3 *mrad*. The spot size aberrations are also small from a perfect cylindrical bend(5). Of course, it is impossible to produce a perfect cylindrical bend in any real ribbed crystal. However, based on the numerical finite element analysis, we have come up with a design which produces very small aberrations. The crystal is to be cut from a 5 inch boule and will be oriented in the <*111*> direction to better than 0.1°. The edge surfaces where the bottom roller are to be located are 1 *mm* thick; the ribs 1 *mm* thick, 6 *mm* long and centered 2 *mm* apart. The thickness of the crystal between the ribs will be 0.75 *mm*. The key findings of the finite element analysis is the determination of the maximum stress, the bending moment required and most importantly the angle of the surface across the face of the crystal. When the crystal is bend to 1.8 *m* the maximum stress is less than one third of the yield stress of *Si*. The bending moment is small enough that the bimetallic strip can bend it and, as we shall show below, the angle errors are very small. There will be two types of errors in the angle of the surface in the non Bragg direction. There will be local oscillations with a period of 2 *mm* since the crystal will bend more between the ribs and less over the ribs. The crystal thickness being comparable to the distance between the ribs should help smooth these out. There will also be a global error if the crystal bends in a curve which is different than a cylinder.

Next we show how to relate the shape calculated by the finite element analysis to the increase in spot size due to these errors. In the small angle approximation the angle of the surface of a perfect cylinder as a function of distance away from its center x, is x/R. The local slope of the surface of the crystal is dy/dx where y is the deflection . Therefore the slope errors in the non Bragg direction are

$$\Delta\alpha(x) = \frac{dy}{dx} - \frac{x}{R} \qquad \text{...(3)}$$

The errors in the horizontal focal position coming from each point x on the surface produced by these angular errors is $R\Delta\alpha(x)$ and is shown in figure 4. The maximum error is less than 0.3 *mm*. This is less than the minimum horizontal spot size cause by the size of the electron beam which at our magnification should give a spot of about 0.5 *mm*. The finite element analysis shows very small compressive stresses on the top surface, most of the bending occurs because of tension in the area between the ribs near the bottom surface. The crystal is presently under fabrication, and we expect to have experimental confirmation in a few weeks.

CONCLUSION

The use of a bimetallic strip as a bending mechanism has proved to be simple, compact and quite easy to use. The use of the live center bending mechanisms has greatly simplified the adjustment of the focus while keeping the crystal from twisting or warping. Fabrication of a crystal with many ribs close together results in an almost perfect surface figure of the crystal.

ACKNOWLEDGEMENTS

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FIGURE CAPTIONS

FIGURE 1. Schematic drawing of the crystal and bender assembly.

FIGURE 2. The horizontal beam size as a function of temperature of the bimetallic strip at 11.5 keV.

FIGURE 3. The measured normalized flux as a function of solid angle of beam falling on the crystal.

FIGURE 4. The error in the focal position as a function of position across the face of the crystal.

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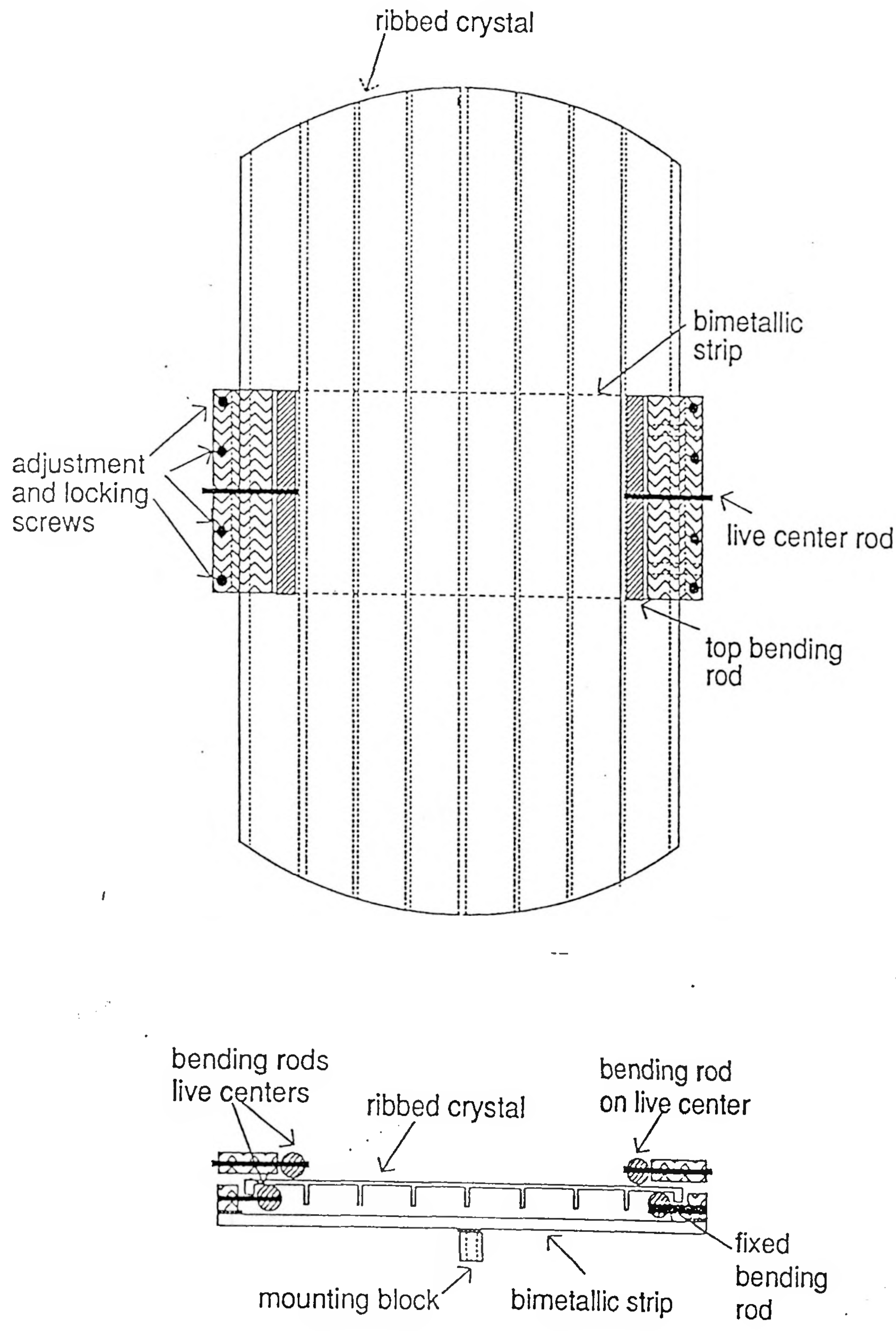

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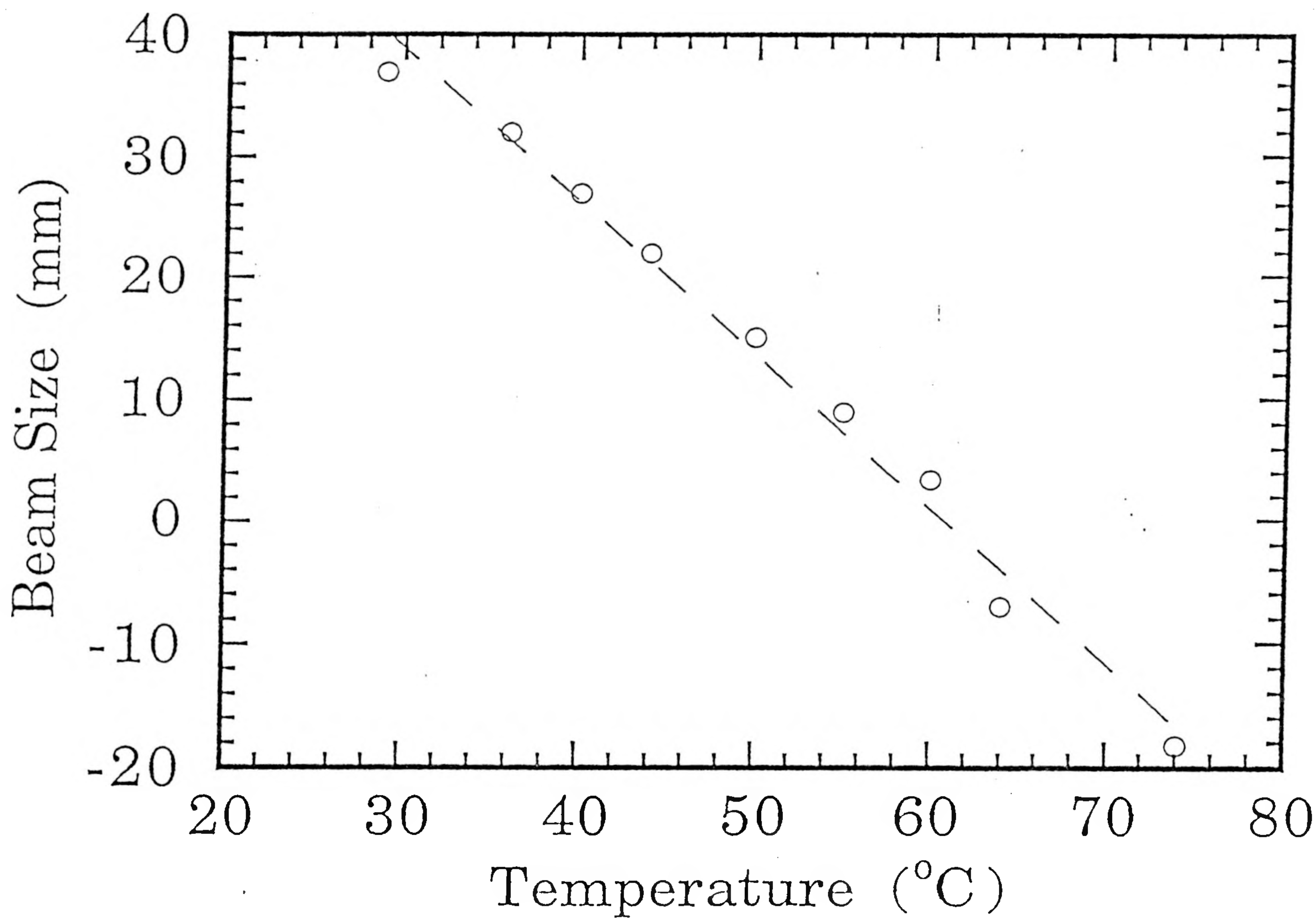

FIGURE 2. The horizontal beam size as a function of temperature of the bimetallic strip at 11.5 keV.

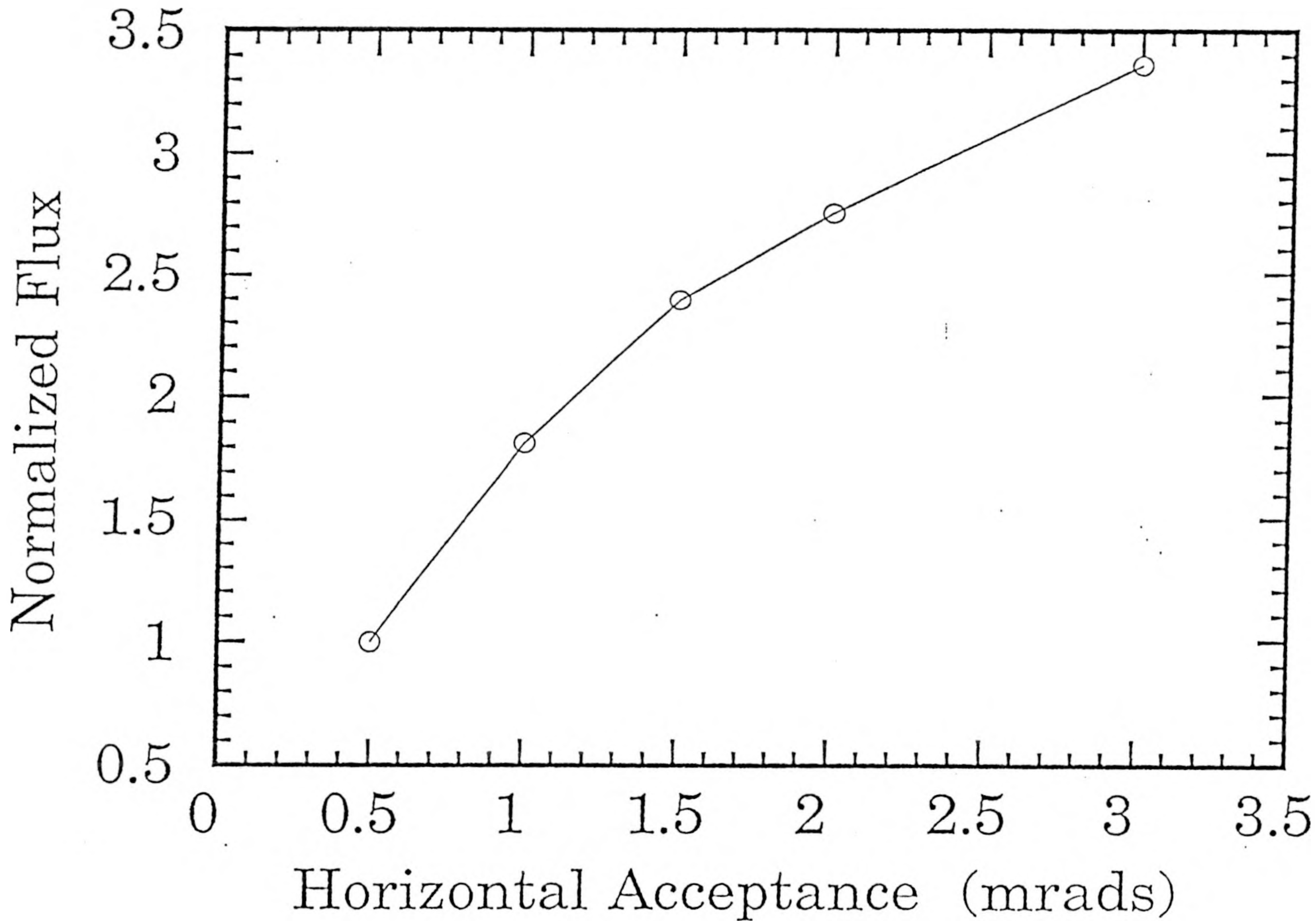

FIGURE 3. The measured normalized flux as a function of solid angle of beam falling on the crystal.

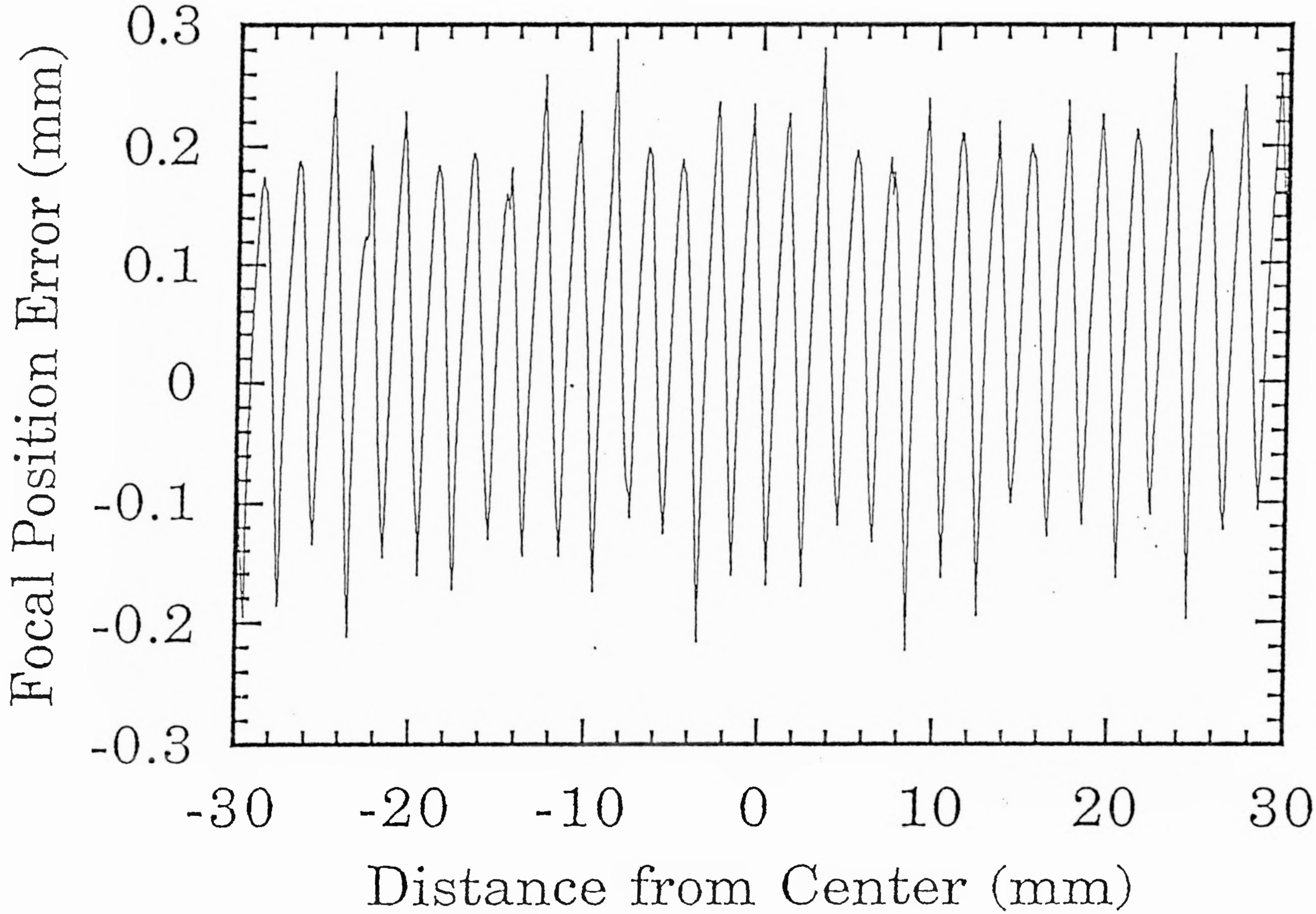

FIGURE 4. The error in the focal position as a function of position across the face of the crystal.