DESIGN OF A LEAF SPRING BENDER FOR DOUBLE LAUE CRYSTAL MONO-CHROMATOR AT SSRF *

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Abstract

A leaf spring bender geometry for water-cooled double Laue crystal monochromator (DLM) is presented. The DLM will be employed to acquire high energy monochromatic X-ray (60keV to 120keV) on the ultra-hard applications beamline at SSRF. A compact bending mechanism is designed in order to get horizontally focused high energy monochromatic X-ray as small as 0.5mm. The bender applies a piece of thin asymmetric crystal and a pair of leaf springs which push the crystal to a sagittally bent radius as small as 1 meter by a pair of symmetry moments. An optimized crystal geometry is achieved by taking into account the meridional and sagittal bendings coupled and defined by the anisotropic elasticity of the asymmetric crystal. Furthermore, thermal slope error and structural stress of the bent crystal are analyzed by finite element method (FEA).

INTRODUCTION

Ultra-hard applications beamline will be constructed during phase II project at Shanghai Synchrotron Radiation Facility (SSRF). High energy focused monochromatic X-ray (60 to 120keV) will be chosen for materials science experiments on ultra-hard applications beamline which is derived from a superconductive wiggler light source whose horizontal divergence is as large as 6 mrad. It is critical how to utilize the light source effectively. The sagittally bent double Laue crystal monochromator (DLM) is a desirable optics for hard X-ray beamline and it's very attractive at high energies for its flux, energy resolution and tunability properties [1,2].

In bent Laue-Laue configuration, as illustrated in Figure 1, the first crystal is arranged in inverse-Cauchois geometry, with the source on its Rowland circle at a distance of F_1 from it. Consequently, a virtual-image point is formed on its Rowland circle at a distance of $R_{m1}\cos(\chi-\theta_B)$ from the crystal. The second crystal is bent so that the virtual image point of the first crystal is on its Rowland circle at a distance of $R_{m2}\cos(\chi+\theta_B)$ from it, while its focus point is at a distance of F_2 from it, where R_{m1} and R_{m2} are the meridional bending radius of the first and second crystal, respectively. Both crystals focus the X-rays sagittally and are in the inverse-Cauchois geometry in the meridional plane. The overall focal length of the DLM is:

$$f_s = R_s/(4\sin\theta_B \sin\chi)$$

when both crystals are bent to radius R_s . θ_B and χ are the Bragg angle and asymmetry angle respectively.

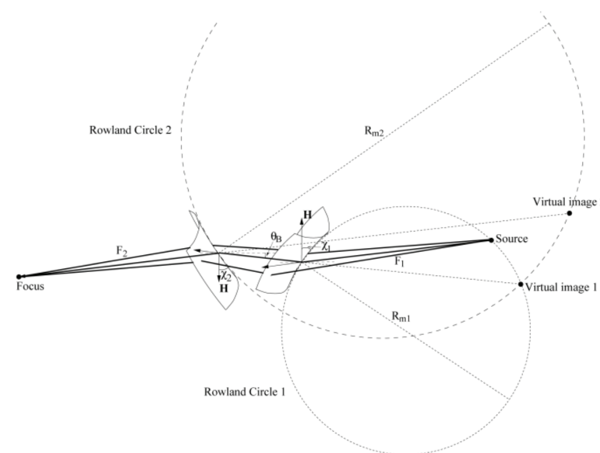

Figure 1: Principle of DLM.

DESIGN AND OPTIMIZATION

Specifications for DLM

The DLM is located at 97 meter from the light source and adopts a pair of thin rectangle crystals with an asymmetric angle of 64.76°. (100) and (311) are the silicon crystal surface and diffraction plane respectively. It will focus the beam horizontally from 30 millimeter to about 500 microns. Main specifications for the DLM is shown in table 1.

Table 1: Specifications for DLM

Parameter	Value
Energy range	60-120 keV
Energy resolution	10^{-3}
Minimum energy step	1eV
Sagittal radius	1-3m
Incident beam size (H×V)	30mm×2.5mm
Beam vertical offset	50mm
Thickness of crystal	1mm
Sagittal residual slope error (RMS)	<6μrad
Meridional residual slope error (RMS)	<10μrad
Vacuum pressure	< 10^{-5} Pa

Optimization for Crystal Dimension

In order to keep the energy resolution at the order of 10^{-3} and obtain a flux of 10^{12} photons/s within the energy range, we set the sample spot at 15 meter (F_2) from the second crystal, due to the limitation for the layout of beamline, whereafter the diffraction plane and asymmetry

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angle are chosen by calculation. Sagittal and meridional curvatures change along with crystal dimensions. The ratio of R_s/R_m depends significantly on the aspect ratio (l/w) of the crystal [3], where l and w are the length and width of the Laue crystal, respectively.

Considering meridional radii are not uniform at different positions of crystal laterally, R_m on the crystal surface at a distance of 7.5mm from center as the optimization. It is optimized by changing the aspect ratio with a constant sagittal radius of 1.78 meter at 100keV.

Poisson ratio is another factor of affect the ratio of $R_s/R_{m.}$ As asymmetry-cut silicon crystal is anisotropic, the Poisson ratio is fixed for a given crystal orientation [4,5]. The length and width of the crystal cutting boundaries are in the [011] and [0-11] direction respectively. The Poisson ratio for the silicon (100) crystal bent around the [011] direction is -0.0642.

An optimized crystal geometry is achieved by taking into account the meridional and sagittal bendings coupled and defined by the anisotropic elasticity of the asymmetric crystal. Figure 2 shows that the bending curvatures depend significantly on the aspect ratio of the crystal. The crystal dimension is 90mm×40mm×1mm (l×w×t). There is 10mm at both sides clamped by each arm.

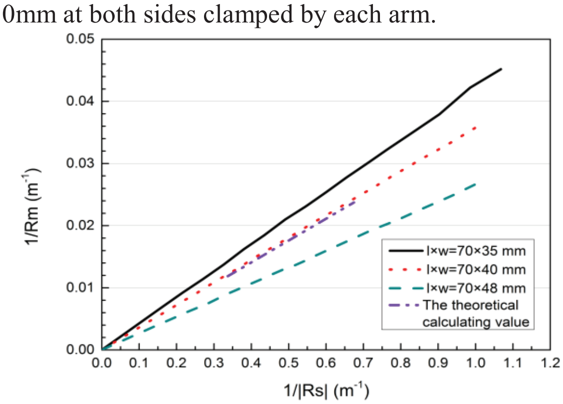

Figure 2: Bending Curvatures Depend on Aspect Ratio.

Leaf Spring Bender

The DLM bender, illustrated in Figure 3, is designed based on a leaf spring bender which was operated on X7B beamline at the National Synchrotron Light Source (NSLS). There are three actions integrated with the bender, which are bending, twist and roll adjustments. Crystal is clamped by a oxygen-free high-conductivity copper spacer inside the groove of each arm which is tightened by screws. The sagittal radius is obtained by pushing one of the two stainless steel leaf springs attached to the clamping blocks while fixing the other one. The bending actuator is a UHV picomotor, which has a desired resolution as small as 30 nm and works with the close-loop control of a DVRT gauge. The flexible springs reduce the local strain and preserve the natural cylindrical bending. There is a twist adjustment on one side of the crystal clamp to ensure that it is parallel to the other side. This adjustment was performed by revolving around the lateral axis of crystal, which is actually a flexible hinge made of QBe2, through a picomotor driven. To correct the downstream beam position laterally when energy is changed, it is essential to set a roll adjustment. Crystal will be rotated around the longitudinal axis, a pair of stainless steel pivots, which are clamped on each sides of the L-shaped plate under the crystal. Specifications for the bender adjustments are listed in table 2.

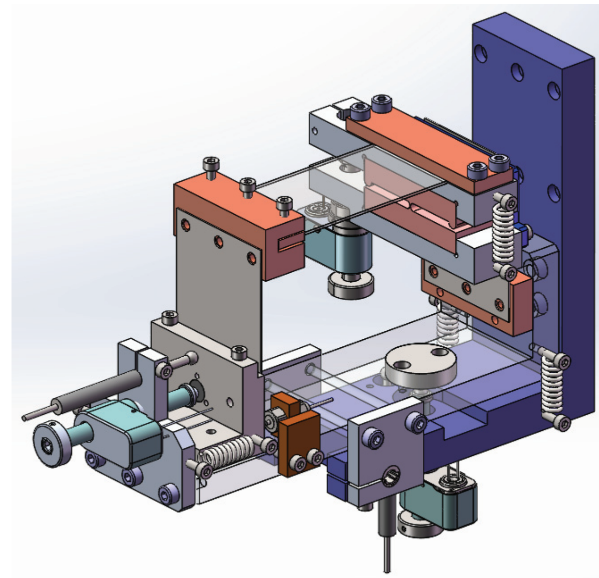

Figure 3: Mechanism of The Leaf Spring Bender.

Table 2: Specifications for The Bender Adjustments

Adjustment	Range	Resolution	Repeatability
Bender	1-3m	0.001m	0.005m
Twist	±1°	0.14arcsec	4.7arcsec
Roll	±2°	0.155arcsec	5arcsec

Residual Slope Error Analysis

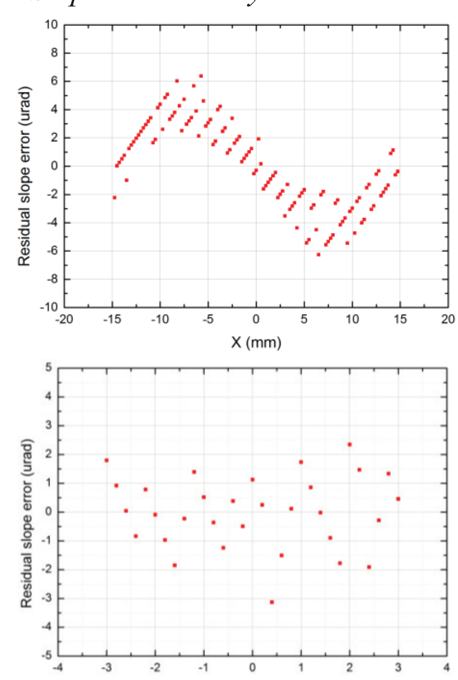

Figure 4: Residual slope error of crystal .

Because of transmission mode, the total heat load absorbed by the first crystal is about 15W with a couple of

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diamond (2.2mm) and SiC (4mm) filters upstream. The maximum thermal density is 0.15 W/mm^2. Crystal holders are water-cooled indirectly by two copper braids which connected with each leaf spring bottom clamps plate. In this way, the maximum temperature and thermal stress of the crystal are 177 centigrade degree and 66.6 MPa.

Large slope error of the crystal will result in lower flux and beam drift on focus point. To keep a reasonable residual slope error sagittally and meridionally for Laue crystal, they are obtained by nonlinear curve fit respectively which take into account the affect of crystal stress, calculated by FEA model, both from bending and heat load.

As illustrated in Figure 4, the sagittal and meridional residual slope error are 3.02μrad (RMS) and 1.25μrad (RMS) respectively.

Tolerance

We have considered and calculated some tolerance situations during manufacturing and installation, which would result in a nonuniform on sagittal radius. Such results are listed in Table 3. The thickness of leaf springs is sensitive to the sagittal radius. It is credible to regard 5 ‰ variation of R_s caused by each parameter as the tolerance limit.

Table 3: Tolerances for The Bender Assembly

Parameter	Dimension	Tolerance
Length of leaf springs	63mm	1mm
Thickness of leaf springs	0.5mm	0.01mm
Angle between bending actuator and leaf spring	90°	±0.015°

SUMMARY

We presented the design and optimization of the leaf spring bender for DLM on ultra-hard applications beamline at SSRF. The surface bending curvatures (1/R_s and 1/R_m) of an asymmetry-cut crystal were calculated numerically using FEA under the small-deformation theory [6]. And analysis and assignment of tolerances are carried out based on installation. Further optical metrology measurements and x-ray tests for the bending curvatures will be planned and carried out.

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