The Finite Element Analysis of the Monochromator Crystal with Water-Cooled Pin-Post Structure

Kiyotaka OHTOMO[1,2] and Tetsuya ISHIKAWA[1,3]

1) SPring-8, Kamigori, Ako-gun, Hyogo 678-12, Japan
2) Quantum Equipment Division, Sumitomo Heavy Industries, Ltd., Shinagawa, Tokyo 141, Japan
3) Faculty of Engineering, University of Tokyo, 2-11-16 Yayoi, Bunkyo, 113, Japan

1. Introduction

For managing the high heat load on the crystal monochromator at the SPring-8 X-ray beamline, R&D of a crystal with water-cooled pin-post structure (Fig.1) [1] combined with the rotated-inclined diffraction geometry[2] is being proceeded. Here we report the evaluation of the optical performance of the crystal by a computer code ODDS[3], which incorporates the strain field from the finite element analysis into Takagi-Taupin equations.

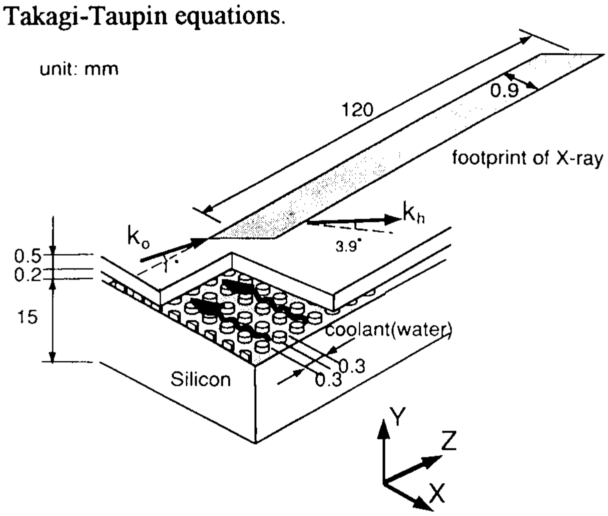

Fig. 1. Scheme of pin-post cooling structure. Substrate, pin posts and surface plate are made of silicon. $\mathbf{k_o}$ and $\mathbf{k_h}$ are the incident and diffraction wave vector. The coordinate is so chosen that the y-axis and z-axis are parallel to the normal vector of crystal surface and the longer edge of footprint of X-rays on crystal surface, respectively.

2. Parameters

A typical X-ray beamline at the SPring-8 are assumed for heat load calculation. The parameters of the linear undulator are listed in Table 1.

Table 1. undurator parameters

insertion device type	linear undurator
K	1.57
period length of magnet poles	3.2cm
total length of magnet poles	4.5m
1st peak photon energy	8keV
photon flux at 8keV on axis	1.45×10^{18}/sec·mrad^2

The X-ray flux has been calculated by SPECTRA[4]. At the downstream of the insertion device, a 100 μm thick carbon filter and a 500 μm thick beryllium window are set and power loss were calculated by OEHL[5]. The monochromator is placed at 35 m from the undulator. By an XY-slit, X-rays are formed into a cross section of 2mm height and 1mm width. Here the power distribution is assumed to be flat within the opening of this slit. The error caused by this assumption is less than 10%.

X-rays enter into the silicon monochromator crystal with the glancing angle of 1 degree. The irradiated X-ray power density is decreased by the filters and inclined geometry. The shape of X-ray's footprint is a narrow parallelogram. Length of longer edge becomes 120 mm and the distance between these two edge becomes 0.9 mm when the photon energy is set to be 8 keV. Absorbed power at silicon crystal, which is also calculated by OEHL, is listed in Table 2.

Table 2 X-ray power densities

power density on axis before filters	329.3kW/mrad^2
power density on axis after filters	311.8kW/mrad^2
power density on crystal surface	4.44W/mm^2
total absorbed power at crystal	356W

The diffraction geometry is Bragg case. The indices and asymmetry factor are selected to be (1,1,1) and 0.2552. The components of the unit vector of $\mathbf{k_o}$, $\mathbf{k_h}$ and diffraction vector $\mathbf{h}$ are listed in Table 3.

Table 3 Components of unit vector of $\mathbf{k_o}$, $\mathbf{k_h}$ and $\mathbf{h}$

	x	y	z
$\mathbf{k_o}$	0.001956	−0.01745	0.9998
$\mathbf{k_h}$	0.4732	0.06839	0.8778
$\mathbf{h}$	0.9533	0.1736	−0.2590

3. Finite element analysis

The finite element analysis have been executed by using finite element method code ANSYS. The analysis consist of two stages and mesh models, because it is impossible to make one mesh model including a small pin-post structure and whole silicon crystal substrate.

Firstly, we made a whole silicon substrate model which have rectangular pin-post structures because of easiness of meshing. In order to save computer memories, mesh interval were set to be twice of the real pin-post interval. A heat transfer coefficient between silicon and water is assumed to be 50000 W/m^2K[1] and water temperature is set to be 25°C. Calculated results on the center of z-axis are shown in Fig. 2, which obviously shows thermal bowing. The bowing looks slightly asymmetric because the X-rays input into the crystal obliquely and the absorbed power increases as z becomes larger.

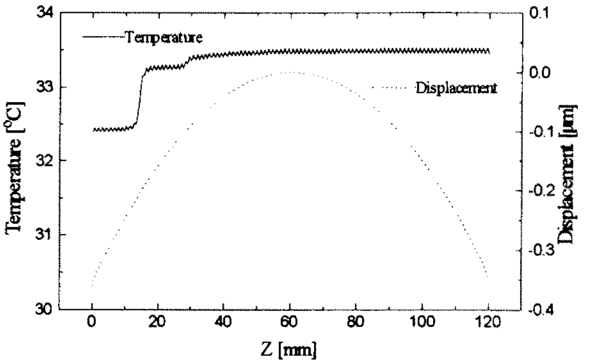

Fig. 2 Calculated temperature and displacement by ANSYS. The reason why temperature changes step by step is that the absorbed power densities were defined at each mesh element.

Secondly one cell of pin-post structure mesh model was composed. This mesh model reflects a manufacturing process i.e. sand-blasting and pin-post shapes are a cone stand. The surface touched with water suffers the water pressure of $3kgf/cm^2$. Another conditions are unchanged from the first model. The displacement distribution of one cell was similar to a sinusoidal modulation with the height of 0.44nm. We assumed that the sum of the displacement data of the first model and the second model correspond to the real displacement.

4. Takagi-Taupin calculation

The expected rocking curves of the crystal with pin-post structure were calculated by using the code ODDS. Figure 3 shows three rocking curves in the rotated inclined geometry. One of them was calculated analytically using dynamical theory of diffraction from the perfect crystals as a reference. The other curves were calculated by ODDS from the perfect and pin-post crystals. Comparing the curves for the perfect crystals, the result of ODDS almost reproduces that of dynamical theory. The rocking curve from the crystal with pin-post structure were calculated using data at z = 60 mm (see Fig. 2). Although the angular width of total reflection decreases slightly, the reflectivity of X-ray is unchanged for W ranging from –0.7 to 0.7.

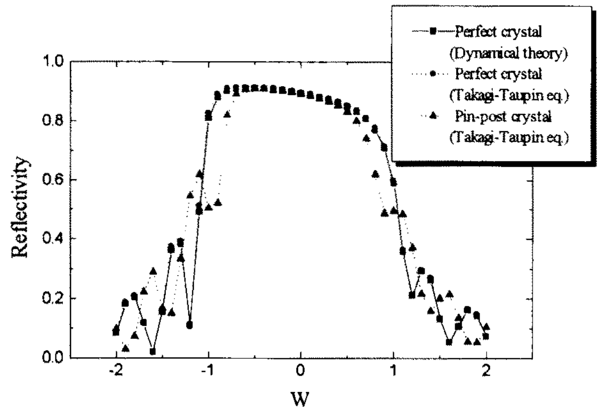

Fig. 3 Rocking curves in the rotated inclined geometry.

Figure 4 shows the rocking curves calculated for asymmetric geometry for the same glancing angle and power density. Appreciable decrease in reflectivity (~20%) is observed. This result indicates that the diffraction geometry affects the optical performance.

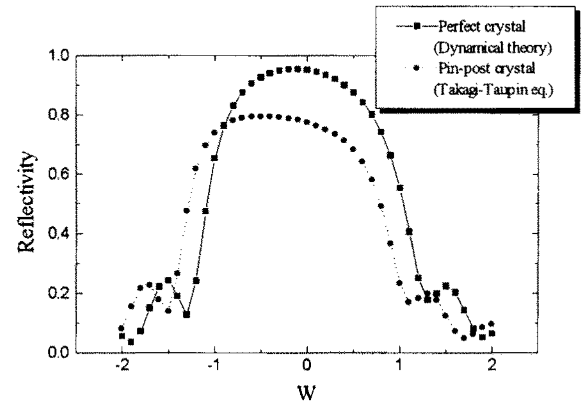

Fig. 4 Rocking curves in the asymmetric geometry.

5. Conclusion

Rocking curves of the silicon crystal with the pin-post structure in the rotated inclined geometry were calculated by using ODDS. The result is almost the same as that for perfect crystals. This leads to a conclusion that the crystal with pin-post structure is of practical use as a monochromator for the SPring-8 undurator.

References

[1] M. Kuroda, H. Yamaoka, and T. Ishikawa, SPring-8 Annual Report **1**, 205 (1994).

[2] T. Uruga et al., Rev. Sci. Instrum. **66**, 2254 (1995).

[3] K. Ohtomo and T. Ishikawa, SPring-8 Annual Report 1, 212 (1994).

[4] H. Kitamura, SPECTRA, Synchrotron Radiation Calculation Program for PC98 Ver.3.0, Jan.1.1994

[5] X. M. Tong, H. Yamaoka, and Y. Sakurai, SPIE Proc. **1739**, 514 (1992).