Thermomechanical Analysis of Front End XY-Slits for the SPring-8 Undulator Beamlines

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1. Introduction

The L-shaped slit of the front end XY-slits assembly installed in the SPring-8 undulator beamlines will be impinged by very intensive photon beam with 451 kW/mrad^2 peak heat flux in the worst case. To handle such high-heat-flux, the L-shaped slit has been designed to be a grazing-incidence configuration so as to stretch out the heat flux on the slit-blade [1]. In order to reduce the heat load on the slit-blade further, the assembly is installed downstream of the pre slit whose circular aperture size is 4 mm in diameter [2] and the graphite filters assembly [3]. Even if the aperture size is limited by the pre slit, this assembly should handle almost 5 kW radiated power when the undulator gap is set to be minimum. So that it is important to understand the thermomechanical properties regarding maximum surface temperature, thermal stress, and thermal distortions of XY-slits under the most severe condition. The finite element analyses were performed for some cases about full irradiation and partial irradiation, in which aperture of the XY-slits assembly was set to enable most photons of fundamental radiation to pass through the XY-slits assembly. The dependence of the surface temperature and the thermal distortion on aperture size have been also studied.

2. Finite element model

In the finite element analyses, a model of the slit-blade was made around the vertex of the L-shaped edge with two cooling channels. The slit-blade was located 30 m from the light source and 2 m downstream of the pre slit. The spatial distribution of the absorbed power was approximated by the equation in Ref.4. Table 1 shows the material properties used in the analyses. We assumed convective heat transfer coefficients of 5000, 10000, 22000, 29000 and 37000 for full irradiation and 29000 W/(m2K) for partial irradiation. Since the Biot modulus is less than 0.5 in the range of heat transfer coefficients assumed, results of the finite element analyses are given in the severe condition because the main cooling channel was quartered with respect to the axis due to the limitation of the number of element. According to the results of flow rate measurements for XY-slits assembly [1], we can expect that the heat transfer coefficient of 20000 W/(m2K) will be readily achieved. A temperature of cooling water was assumed to be 30 ˚C.

3. Results and discussion

In the thermal and thermomechanical analyses, the effect of heat-load reduction by pre slit was incorporated by forcing the circular aperture to be 4 mm in diameter. In the case of full irradiation, only the vertical blade or the horizontal blade was irradiated by photon beam. Both of the blades, on the other hand, were irradiated simultaneously for partial irradiation because a couple of the L-shaped slits was positioned so as to shape the photon beam into a rectangle.

3.1 Thermal analyses for full irradiation

Maximum temperature on the blade surface and on the surface of cooling channel for some different heat transfer coefficients are shown in Table 2. Reduction of the heat-load by the pre slit will decreases the maximum temperature about 6% for realistic condition, i.e. H > 20000 W/(m^{2}K). In the case of irradiation onto the horizontal blade, the footprint of the beam extends much more than the case of vertical blade irradiation so that the resulting maximum temperature with same heat transfer coefficient is less severe. By considering the utilization of the XY-slits assembly with heat transfer coefficient larger than 20000 W/(m2K), maximum temperature on the blade will be smaller than 300 ˚C by full irradiation with very intensive undulator beam for minimum gap.

3.2 Thermal and thermomechanical analyses for partial irradiation

Maximum surface temperature and thermal distortions along L-shaped edge of the slit blade under partial irradiation were simulated at various aperture size. The results are shown in Table 3. In the case of zero aperture size, the photon beam is cut by the upstream slit blade and the downstream one with the ratio of 3 : 1 respectively, and the XY-slits assembly shuts off the beam. According to the analyses, maximum thermal distortions along the edge will be 25 µm on the vertical blade and 48 µm on the horizontal blade. Figure 1 shows curves about the displacement of the edge from its origin along the edge. Therefore aperture size of the assembly will be changed little due to thermal distortions.

4. Life cycle number evaluation

By adapting the Manson-Coffin curve for copper to evaluate a life cycle number roughly [5], we can suppose a cycle number to failure of greater than 20000 for 0x0 (mm^2) aperture size.

References

[1] M.Oura et al., in this issue.

[2] S.Takahashi et al., SPring-8 Annual Report 1995, p.183 and in this issue.

[3] Y.Sakurai and H.Kitamura, SPring-8 Annual Report 1994, p.52

[4] H.Sakae et al., SPring-8 Annual Report 1994, p.168

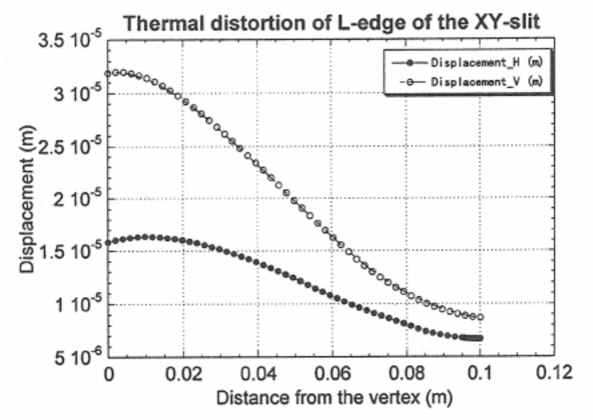

Fig.1 Thermal distortion of L-edge of XY-slit

Table 1 Material properties of Glidcop

	Glidcop
Thermal conductivity, K (W/(mK))	365
Thermal expansion coefficient, α (1/K)	16.6×10^{-6}
Young's modulus, E (GPa)	130
Poisson ratio, ν	0.326

Table 2-1 Full irradiation onto the vertical blade

H (W/(m^{2}K))	Without pre slit		With pre slit	
	T_b^{max} (°C)	T_c^{max} (°C)	T_b^{max} (°C)	T_c^{max} (°C)
5000	737	-----	643	-----
10000	454	-----	412	-----
22000	298	177	278	164
29000	267	144	250	135
37000	245	-----	231	-----

Table 2-2 Full irradiation onto the horizontal blade

H (W/(m^{2}K))	Without pre slit		With pre slit	
	T_b^{max} (°C)	T_c^{max} (°C)	T_b^{max} (°C)	T_c^{max} (°C)
22000	247	150	230	140

H ; Heat transfer coefficient
T_b^{max} ; Maximum temperature on the blade surface
T_c^{max} ; Maximum temperature on the surface of cooling channel

Table 3 Maximum temperature and thermal distortions along L-shaped edge under partial irradiation

Aperture size (mm^2)	T_b^{max} (°C)	T_c^{max} (°C)	Thermal distortions along edge of the blade (μ m)	
			δ_V	δ_H
0 (0 x 0)	246.38	126.33	24.9	47.8
0.5 (1 x 0.5)	222.69	114.67	21.4	42.0
1.6 (1.788 x 0.894)	188.68	99.88	17.4	34.3
2 (2 x 1)	179.42	95.92	16.4	32
2.8 (2.366 x 1.183)	159.26	87.15	14.1	27.5

T_b^{max} ; Maximum temperature on the blade surface
T_c^{max} ; Maximum temperature on the surface of cooling channel
δ_V ; Displacement along the edge of the vertical blade
δ_H ; Displacement along the edge of the horizontal blade