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THE HEAT LOAD CALCULATION IN THE GRATING-BASED BEAMLINE AT HEFEI ADVANCED LIGHT FACILITY (HALF) *

Zimeng Wang†, Jie Chen, Xuewei Du, Qiuping Wang and Donglai Feng, National Synchrotron Radiation Laboratory, University of Science and Technology and China, Hefei, Anhui, China

Abstract

The light emitted by the 4th generation synchrotron radiation (SR) light source is more concentrated. Therefore, its heat load causes more severe thermal deformation on the beamline optics than the 3rd generation SR light source. The requirement on the optical element surface quality is also higher to achieve better spectral resolution, coherence preservation and focusing. The precise calculation of heat load on the optical elements is fundamental for the thermal analysis including cooling method and thermal deformation simulation. A heat load calculation code has been developed for SR beamline optics, which consists of SR source calculation module for precise power density distribution, mirror reflectivity module and grating efficiency module. Therefore, it can be applied to mirrors, crystals and gratings.

This code has been used to calculate the heat load of BL10 - the Test Beamline optics at Hefei Advanced Light Facility (HALF). The heat absorbed by the first three optical elements are precisely calculated, including a toroidal mirror, a plane mirror and a plane grating.

INTRODUCTION

To quantitatively calculate the heat load on the synchrotron radiation (SR) beamline optical elements, it is necessary to combine the angular distribution calculation of the source power density with the calculation of optical element transmission efficiency, including the reflectivity of the mirrors and the diffraction efficiency of the gratings. SRCalc [1, 2] is one of the software that calculates the optical elements. However, SRCalc only contains mirror and crystal heat load calculation. Currently, there is still no software available that enables the calculation of grating heat load. Therefore, in beamline design, the calculation of grating thermal load is often estimated.

The light source and efficiency calculation programs mentioned earlier have been completed. Therefore it is possible to achieve precise calculations of the heat load for all optical elements, including the gratings. This paper will take the Test Beamline (BL10) in Hefei Advanced Light Facility (HALF) [3] as an example of heat load calculation including mirrors and gratings.

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† zimeng@ustc.edu.cn

HALF TEST BEAMLINE HEATLOAD CALCULATION

HALF is a 4th generation SR light source with the emittance of 73.2 pm•rad in both x and y directions. The storage ring energy is 2.2 GeV and the current is 350 mA. The Test Beamline (BL10) is an undulator-based beamline. The undulator consists of 98 periods with 40 mm as its period length.

The Test Beamline aims to use a grating monochromator with extra high spectral resolving power of 10^5@400 eV, ranging from 275 eV to 1500 eV in the first-version optical design. High-quality optical surface is required with overall slope error from 100 – 200 nrad (rms). In order to control the thermal-induced slope error, the precise heat load distribution absorbed by the optical elements should be calculated, which is fundamental for cooling system design and simulation. Here, the undulator source angular power density distribution up to 80th order is calculated.

Optical Design

The Test Beamline adopted the collimated SX-700 grating monochromator as shown in the Fig. 1. The toroidal mirror M_1 collimates the source light in the vertical direction and focus it onto the exit slit in the horizontal direction. The plane mirror (PM) reflects the incoming light from M_1 to the centre of plane grating GR. The light diffracted from GR is focused by the cylindrical mirror M_2 to the exit slit in the vertical direction. The grazing incident angle and M_1 and M_2 are 2°.The heat load of M_1, PM and GR will be calculated at 275 eV.

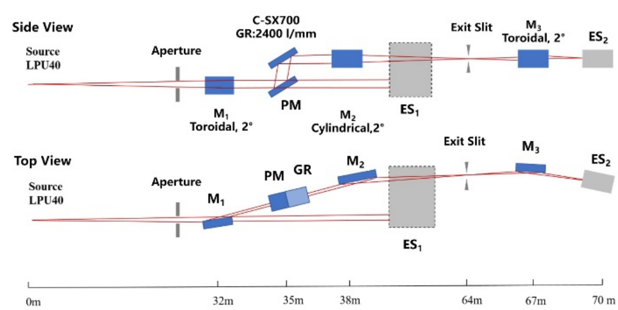

Figure 1: The beamline optical design.

Mirror Heat Load Calculation

The heat load of the mirrors is calculated by combining the source property and mirror reflectivity calculation. The spatial power density distribution can be calculated from the angular distribution of the source power density $\frac{d^2P^n_{\sigma,\pi}}{d\varphi d\psi}$ [4]:

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$$\left.\frac{d^2P^n_{\sigma,\pi}}{dxdy}\right|_{\mathrm{M_1}} = \sum_n \frac{d^2P^n_{\sigma,\pi}}{d\varphi d\psi}\times\frac{\sin\theta_{\mathrm{M_1}}}{r_1^2}$$

Here, $r_1 = 34$ m is the distance from source to $\mathrm{M_1}$, $\theta_{\mathrm{M_1}} = 2^{\circ}$ is the grazing angle of $\mathrm{M_1}$; n is the order of the undulator, σ and π indicate the light polarization. The photon energy of the n^{th} order at position (x,y) is $E_n(x,y)$. The mirror reflectivity at grazing angle θ for photon energy of $E_n(x,y)$ is $R_{\sigma,\pi}(\theta, E_n(x,y))$. Therefore, the reflected power density at (x,y) by $\mathrm{M_1}$ can be calculated by:

$$\left.\frac{d^2P^n_{\sigma,\pi}}{dxdy}\right|_{\mathrm{M_1\_refl}} = \left.\frac{d^2P^n_{\pi,\sigma}}{dxdy}\right|_{\mathrm{M_1}}\times R_{\sigma,\pi}\left(\theta_{\mathrm{M_1}}, E_n(x,y)\right)$$

Here, $\mathrm{M_1}$ reflects the light in the horizontal direction. Therefore, the σ-polarized light at source incidents on the $\mathrm{M_1}$ as π-polarized light, which is same to the π-polarized light from source.

Deducted the reflected power density by $\mathrm{M_1}$ from the incident power density to $\mathrm{M_1}$, the absorbed power density can be calculated by the following equations. Figure 2 shows the calculation result of the $\mathrm{M_1}$ heat load.

$$\left.\frac{d^2P^n_{\sigma,\pi}}{dxdy}\right|_{\mathrm{M_1\_absorb}} = \left.\frac{d^2P^n_{\sigma,\pi}}{dxdy}\right|_{\mathrm{M_1}} - \left.\frac{d^2P^n_{\sigma,\pi}}{dxdy}\right|_{\mathrm{M_1\_refl}}$$

$$\left.\frac{d^2P}{dxdy}\right|_{\mathrm{M_1\_absorb}} = \sum_{\sigma,\pi}\sum_{n=1}^{80}\left.\frac{d^2P^n_{\sigma,\pi}}{dxdy}\right|_{\mathrm{M_1\_absorb}}$$

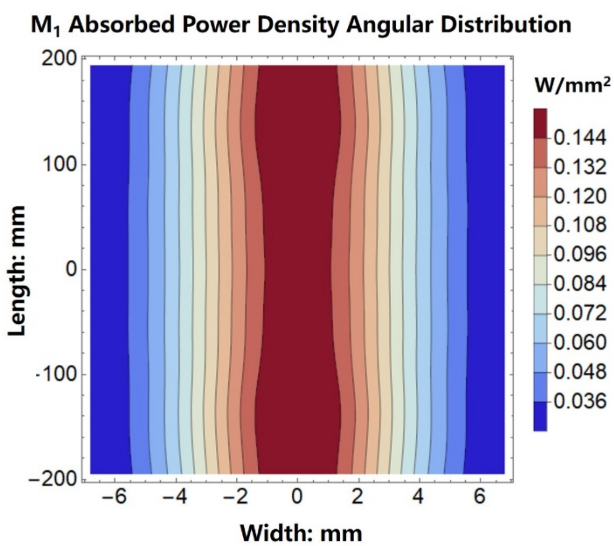

Figure 2: The heat load absorbed by the mirror $\mathrm{M_1}$.

The reflected light by $\mathrm{M_1}$ incidents on the plane mirror PM at grazing angle $\theta_{\mathrm{PM}} = 4.58^{\circ}$. PM is $r_{cm} = 3\ m$ away from $\mathrm{M_1}$. The incident power density on PM can be calculated from the optical geometry:

$$\left.\frac{d^2P^n_{\pi,\sigma}}{dxdy}\right|_{\mathrm{PM}} = \left.\frac{d^2P^n_{\pi,\sigma}}{dxdy}\right|_{\mathrm{M_1\_refl}}\times\frac{\sin\theta_{\mathrm{PM}}}{\sin\theta_{\mathrm{M_1}}}\times\frac{r_{cm}}{r_{1t}-r_{cm}}$$

Here, $r_{1t} = 32$ m is the distance between $\mathrm{M_1}$ and the exit slit. The reflected and absorbed power density by PM is calculated in the same way as $\mathrm{M_1}$. Figure 3 shows the calculated heat load on PM:

$$\left.\frac{d^2P^n_{\sigma,\pi}}{dxdy}\right|_{\mathrm{PM\_refl}} = \left.\frac{d^2P^n_{\pi,\sigma}}{dxdy}\right|_{\mathrm{PM}}\times R_{\sigma,\pi}\left(\theta_{PM}, E_n(x,y)\right)$$

$$\left.\frac{d^2P}{dxdy}\right|_{\mathrm{PM\_absorb}} = \sum_{\sigma,\pi}\sum_{n=1}^{80}\left(\left.\frac{d^2P^n_{\pi,\sigma}}{dxdy}\right|_{\mathrm{PM}} - \left.\frac{d^2P^n_{\sigma,\pi}}{dxdy}\right|_{\mathrm{PM\_refl}}\right)$$

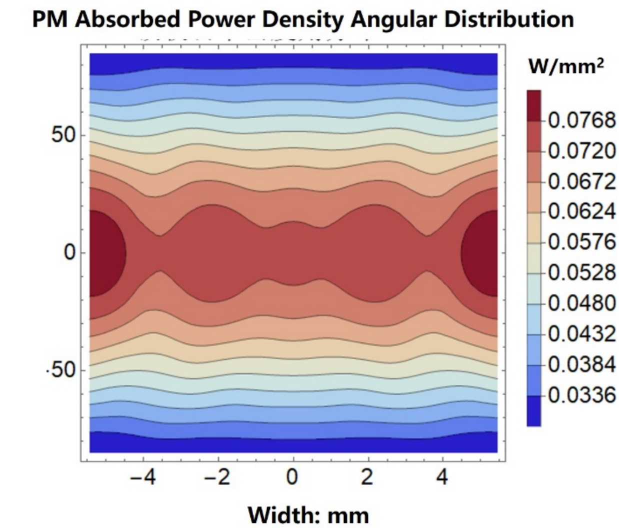

Figure 3: The heat load absorbed by the mirror PM.

Grating Heat Load Calculation

The reflected light from the plane mirror incident on the grating at an incident angle of $\alpha = 89.3^{\circ}$. The outgoing light from grating consists of the reflected light and the diffracted light. The absorbed power density distribution can be calculated.

$$\left.\frac{d^2P^n_{\sigma}}{dxdy}\right|_{\mathrm{gr}} = \left.\frac{d^2P^n_{\sigma,\pi}}{dxdy}\right|_{\mathrm{PM\_refl}}\times\frac{\cos\alpha}{\sin\theta_{\mathrm{PM}}}$$

$$\left.\frac{d^2P}{dxdy}\right|_{\mathrm{gr\_out}} = \sum_{\sigma,\pi}\sum_{n=1}^{80}\left[\sum_{m=1}^{3}\left.\frac{d^2P^n_{\sigma}}{dxdy}\right|_{\mathrm{gr}}\times Eff_{m,\sigma,\pi}(\alpha, E_n) + \left.\frac{d^2P^n_{\sigma,\pi}}{dxdy}\right|_{\mathrm{gr}}\times R_{\sigma,\pi}\left(\frac{\pi}{2}-\alpha, E_n\right)\right]$$

Here, $Eff_{m,\sigma,\pi}(\alpha, E_n(x,y))$ are the m^{th} order diffraction efficiencies [5] for photon energy $E_n(\mathrm{x,y})$ at incident angle α with σ- and π-polarized light. For $m > 3$ order diffraction, the efficiency is close to zero. Therefore Only $m = 1, 2, 3$ diffraction orders are calculated. The absorbed power density by the grating can be calculated. Figure 4 shows the grating heat load.

$$\left.\frac{d^2P}{dxdy}\right|_{\mathrm{gr\_absrob}} = \left.\frac{d^2P}{dxdy}\right|_{\mathrm{gr}} - \left.\frac{d^2P}{dxdy}\right|_{\mathrm{gr\_out}}$$

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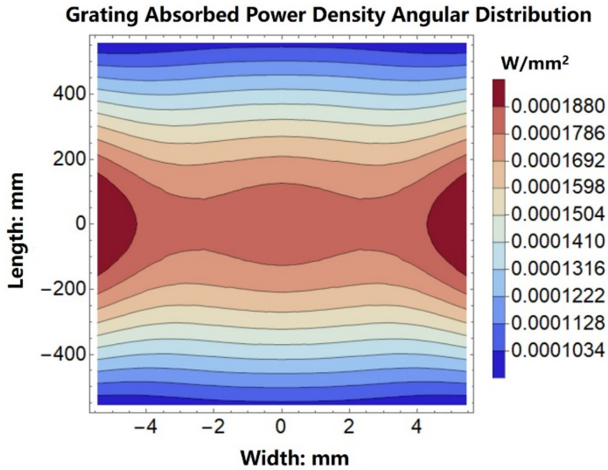

Figure 4: The heat load absorbed by the grating GR.

CONCLUSION

A heat load calculation method for SR beamline optics is introduced. The heat load distribution on mirror M_1, PM and grating Gr in BL10 Test Beamline were calculated. The mirror calculation results are matched with SRCalc. Therefore, heat load on all mirrors and gratings can be calculated precisely. Therefore, heat load on all mirrors and gratings can be calculated precisely.

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REFERENCES

[1] R. Reininger, *SRCalc*, 2001, unpublished.

[2] L. Rebuffi, X. Shi, M. S. Rio and R. Reininger, “A ray-tracing algorithm for *ab initio* calculation of thermal load in undulator-based synchrotron beamlines”, *J. Synchrotron Radiat.*, vol. 27, pp. 1108-1120, Sep. 2020.

[3] Z. Sun, G. Feng, X. Liu, “Construction of Hefei advanced light facility begins”, *The Innovation*, vol. 4, issue 6, 100514, Sep. 2023.

[4] K-J. Kim, “Characteristic of Synchrotron Radiation”, *AIP Conference Proceedings*, vol. 184, pp. 565-632, Apr. 1989.

[5] V. S. Valdes, W. R. McKinney and C. Palmer, “The differential method for grating efficiencies implemented in mathematica™”, *Nucl. Instrum. Methods Phys. Res. Sect. A*, vol. 347, issues 1-3, pp. 216–219, Aug. 1994.