The Heat Load Calculation in the Grating-based Beamline at Hefei Advanced Light Facility (HALF)

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Abstract

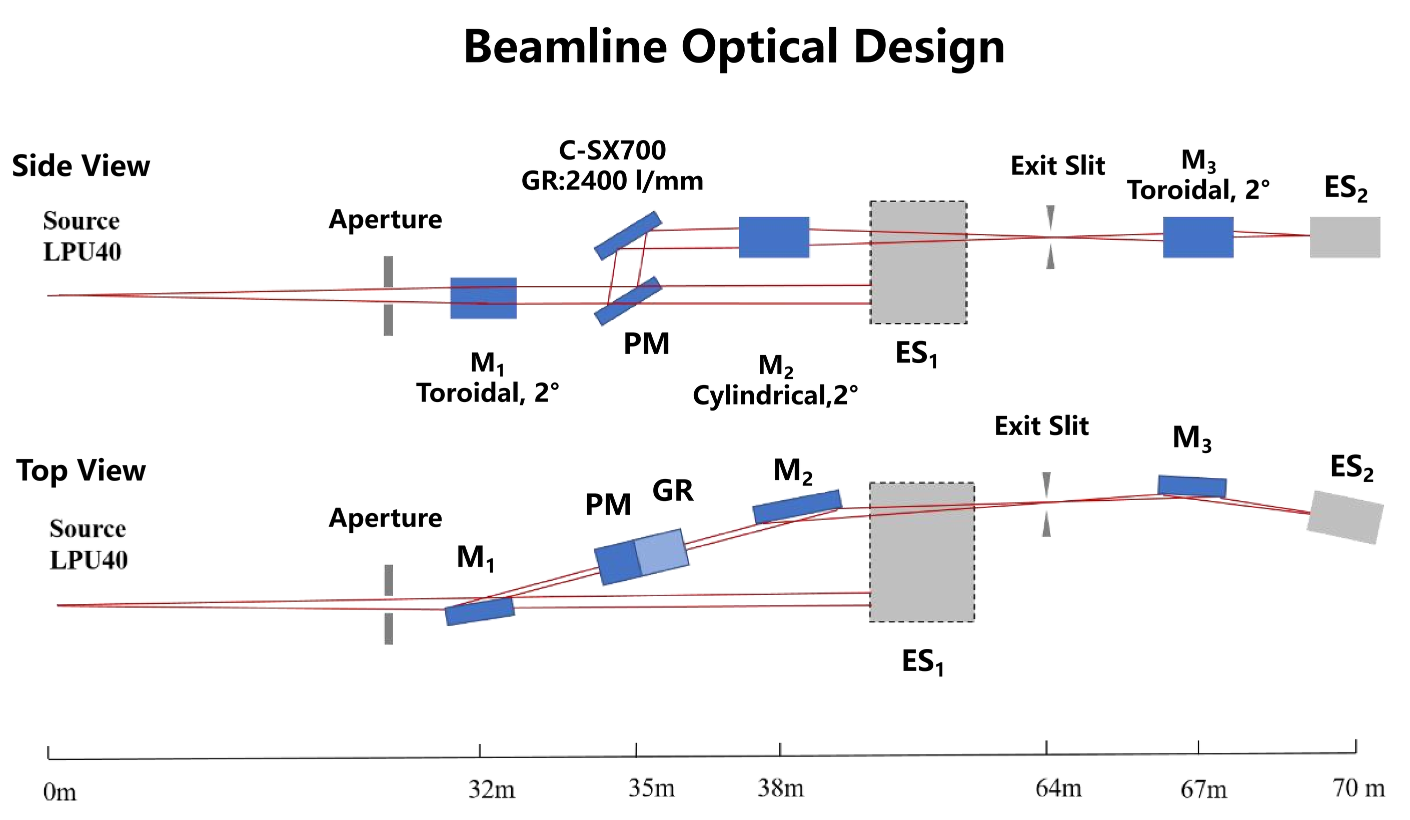
The light emitted by the 4th generation synchrotron radiation(SR) light source is more concentrated. Therefore, its heat load causes more severe thermal deformation on the beamline optics than the 3rd generation SR light source. The requirement on the optical element surface quality is also higher to 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 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.

HALF Test Beamline Heatload Calculation

HALF-BL10 Test Beamline aims to build an grating monochromator with extra high spectral resolving power of 10^5@400 eV, ranging from 250 eV to 2000 eV. 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.

HALF Test Beamline Optical Design



The Beamline adopted the collimated SX-700 grating monochromator as shown in the figure. The toroidal mirror M1 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 M1 to the center of plane grating GR. The light diffracted from PG is focused by the cylindrical mirror M2 to the exit slit in the vertical direction. The heat load of M1, PM and PG will be calculated.

Mirror Heat Load Calculation: M_1 and PM

Incident light power density distribution on M_1 (n: harmonics; σ/π: polarization)

$$\left.\frac{d^2P^n_{\sigma,\pi}}{dxdy}\right|_{M_1} = \sum_{n=1}^{80} \frac{d^2P^n_{\sigma,\pi}}{d^2\Omega} \times \frac{\sin\theta_{M_1}}{r_1^2}$$

Reflected power density distribution by M_1

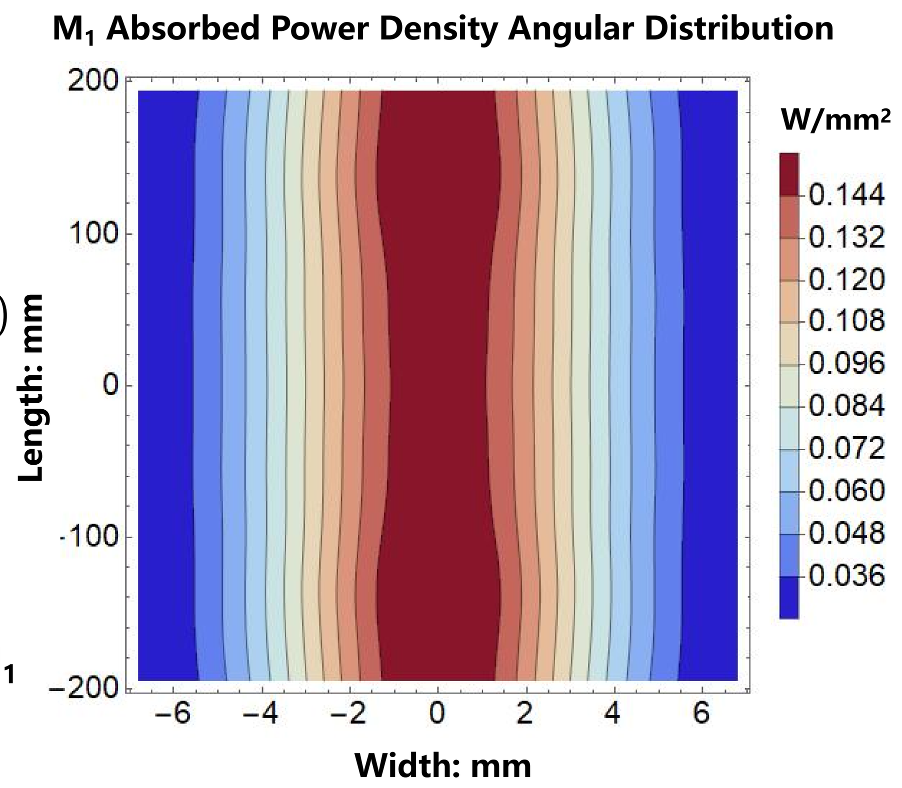
$$\left.\frac{d^2P^n_{\sigma,\pi}}{dxdy}\right|_{M_1\_refl} = \left.\frac{d^2P^n_{\pi,\sigma}}{dxdy}\right|_{M_1} \times R_{\sigma,\pi}\left(\theta_{M_1}, E_n(x,y)\right)$$

Absorbed power density distribution by M_1

$$\left.\frac{d^2P^n_{\sigma,\pi}}{dxdy}\right|_{M_1\_absorb} = \left.\frac{d^2P^n_{\sigma,\pi}}{dxdy}\right|_{M1} - \left.\frac{d^2P^n_{\sigma,\pi}}{dxdy}\right|_{M_1\_refl}$$

Total absorbed power density distribution by M_1

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

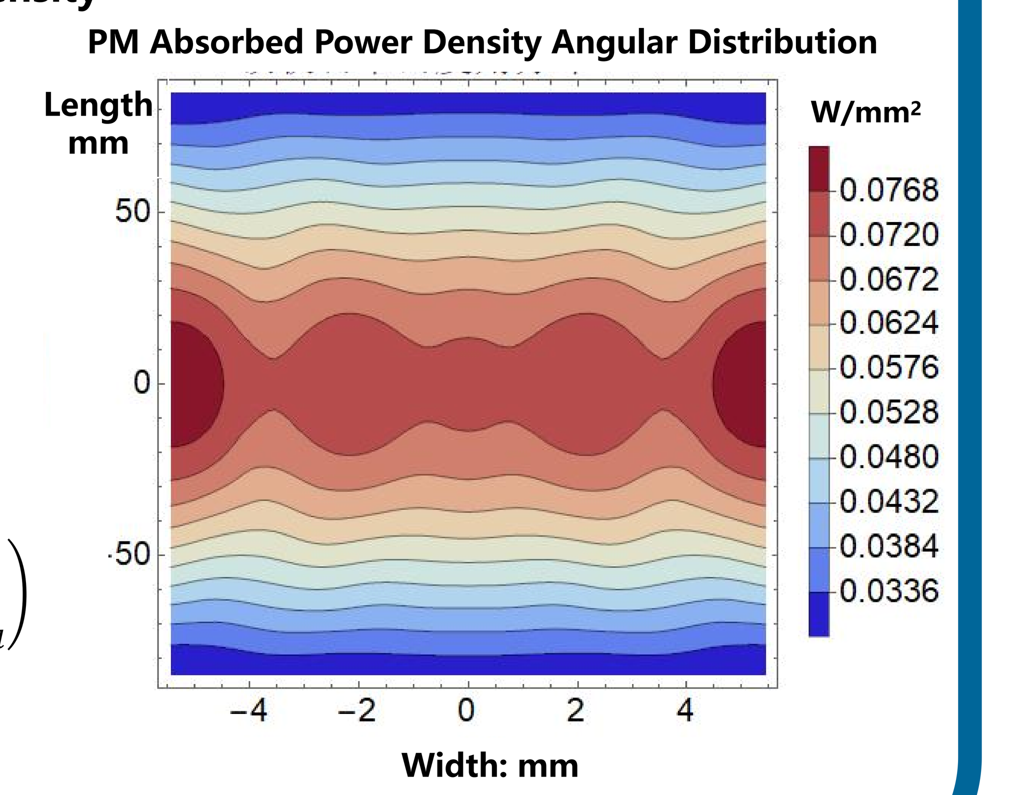


Incident/reflected/absorbed light power density distribution on PM:

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

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

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



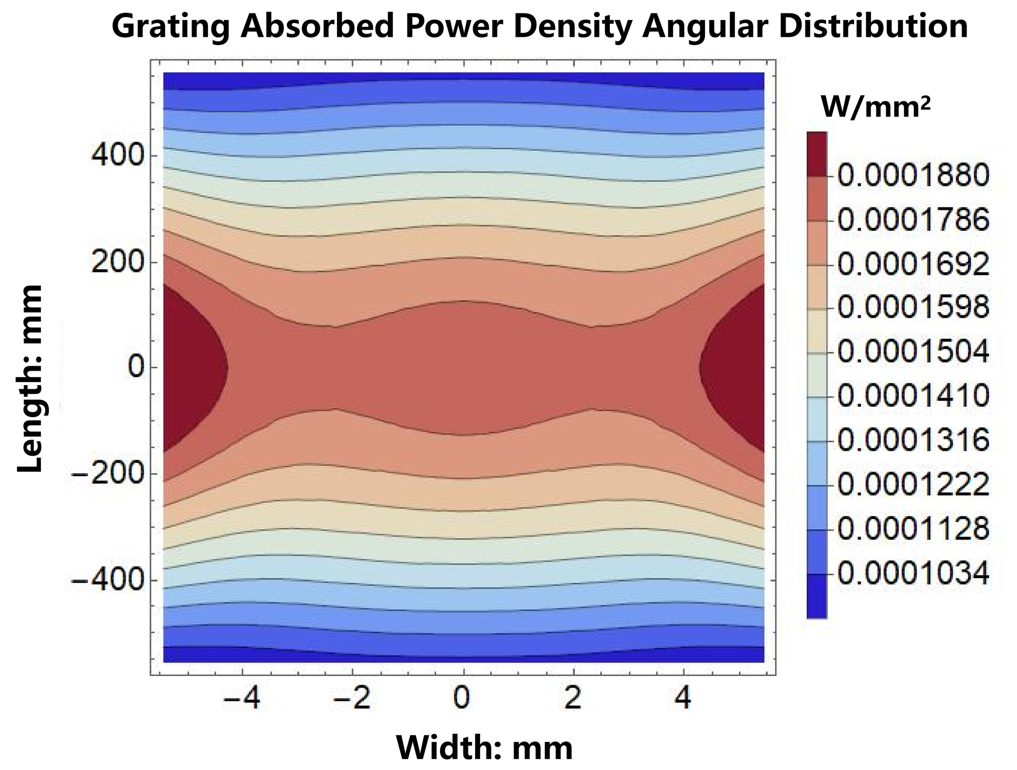
Power density distribution calculation results are matched with SRCalc

Grating Heat Loat Calculation

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

The incident light on the grating is calculated from the reflected light from PM. The outgoing light from grating consists of the reflected light and the diffracted light. The absorbed power density distribution can be calculated :

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



Conclusion

A heat load calculation code for SR beamline optics is introduced. The heat load distribution on mirror M1, 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.

Reference

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[3] Z. Sun, G. Feng, X. Liu, The Innovation, 4 (6), 100514 (2023).