Study on cooling for optical parts with high heat loads at the SSRF

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Abstract: The performance of optical elements in the beamline is very sensitive with the deformation caused by high heat loads, which require special cooling methods to preserve the quality of the photon beam. In the paper, the thermal analyses of two kinds of mirrors are presented. One of mirrors made of silicon is used to collimate X-ray; another mirror made of copper is used to reflect infrared light. Different indirect water cooling methods, side cooling and bottom cooling, are adopted for them. By means of optimization design using Ansys software, better slope of two mirrors is achieved. Optimization procedures for reducing their slope error are also described.

1. Introduction
The Shanghai Synchrotron Radiation Facility (SSRF) in China is an intermediate energy, third generation synchrotron light source [1]. With an energy of 3.5 GeV and beam current of 300mA, it provides photon beams of high brightness for research in life sciences, materials science, earth and environmental sciences and many other fields. High energy results in high heat load on many components in a beamline. Besides front-end components, optical parts usually absorb high thermal load from X-ray source and their surface will deform, which have bad effect on the beamline performance. So the cooling methods must be used to reduce such negative impact. As a rule, slope error on the optical surface can indicate its deformation and is expected to be as small as possible [2]. Now both direct and indirect cooling methods [3-7] have been used widely. Suitable method should be selected in different situations.
In the paper, the thermal analyses of two kinds of mirrors are presented. One of mirrors made of silicon is used to collimate X-ray; another mirror made of copper is used to reflect infrared light. In the following paragraph, finite element analysis for these mirrors using Ansys software [8] will be described, respectively.

2. Collimation mirror
Figure 1 shows the 3D model of collimation mirror made of single crystal silicon and cooling blocks made of OFHC copper. Three dimensions of the mirror are 30mm (X) × 250mm (Y) × 25mm (Z). When X-ray energy from the elliptically polarized undulator (EPU) is 250ev, the maximum power and power density absorbed by the mirror are 85.7W and 0.13W/mm². Footprint size is 3mm (X) × 230mm (Y), power density distribution on the mirror is shown in Figure 2. The equivalent film coefficient between mirror and cooling block is 3.0E-3 W/ (mm²·°C), reference temperature for 30°C.
2.1. Optimization design
The length and width of contact area are parameterized and designated as design variables, DS_LENGTH and DS_HEIGHT, respectively. The maximum tangential slope error along the mirror centerline acts as objective function, my_MaxYSlopeError. Then optimization design is performed by Ansys DesignXplorer. The relation curves between the size of contact area and the maximum slope error in tangential direction, shown in Figure 3 and 4, are obtained.

| Scheme | Height | Length |
|--------|--------|--------|
| A      | 10mm   | 250mm  |
| B      | 6mm    | 215mm  |

In order to analyze how the shape of the contact area has effect on slope error on mirror, two kinds of schemes A and B shown in Table 1 has been chosen, in which scheme A is the traditional scheme, the length of contact area and mirror is equal, but in scheme B the length of contact area is smaller...
than Footprint’s length. After performing the thermal analysis on the two schemes, respective temperature distributions are shown in Figure 5 and 6.

It is can be seen from Figure 5 the maximum temperature is located in the centre of mirror if the length of contact area is bigger than Footprint’s; if the length of contact area is smaller than Footprint’s, maximum temperature is far away from the centre of mirror, shown in Figure 6. The slope error values for above two schemes are listed in Table 2. Among them, not only the maximum slope error in tangential for the scheme B is smaller, but also is its RMS value also. Moreover the slope error values in sigittal direction are slightly different. So the scheme B is better.

Table 2. Slope error value for two Schemes.

| Scheme | Sagittal | Tangential |
|--------|----------|------------|
|        | Maximum value | RMS   | Maximum value | RMS   |
| A      | 3.57μrad | 3.37μrad | 5.84 μrad | 2.39μrad |
| B      | 3.60μrad | 3.45μrad | 2.86μrad | 0.56μrad |

3. Infrared mirror

Many Infrared beamlines have been built in the world [9-11]. At the SSRF this mirror is the first part in Infrared beamline, which will withstand all the photon flux from a bending magnet source, including the X-ray component. So it is essential to perform thermal analysis for this mirror design.

3.1. FEA model

X-ray beam strikes the infrared mirror at an angle of 45 degree to the mirror surface. By Calculation, the mirror will absorb thermal power of 1642 watts, whose distribution is shown in Figure 7. In order to lower total heat load shed on mirror significantly, a 2.5mm slot symmetric with respect to the y-axis as shown in Figure 8 is designed to allow the most of high-energy radiation to pass through. Origin of coordinates is located in the slot, while the x-axis lies in the mirror surface. Finally, the infrared mirror only absorbs heat power of 33.6 watts. Taking mechanical mount into account, a bottom-cooling method is used for this mirror. The infrared mirror made of Glidcop is fixed to the cooling OFHC block with four screws. And the water pipe and the cooling block are weld together.

Figure 7. Power density distribution on the mirror

Figure 8. 3D model for the infrared mirror and the cooling block.

The thermal contact conductance between the mirror and cooling block is 3e-3 W/(mm²·°C), while that value between the copper pipe and cooling block is 5e-3 W/(mm²·°C). And the equivalent film coefficient is 3.0E-3 W/(mm²·°C).

3.2. FEA results

If 30°C water is used as a coolant, the maximum slope error RMS in the tangential direction is about 70μrad, which is far beyond expectation. To meet the design requirement of the infrared mirror, other two different temperature cooling water at 10°C and 20°C are used in thermal analysis, respectively.
Their temperature distribution and directional deformation are shown as Figure 9 and 10. Because the cooling block and water pipe is non-symmetry about y axis, the temperature distribution on the mirror is asymmetry, also. From table 3, it can be seen that both directional deformation and tangential slope error RMS are smallest when cooling water temperature is 10°C. And these results are satisfying for the infrared beamline.

![Figure 9. Temperature distribution for infrared mirror and cooling block](image)

![Figure 10. Directional Deformation (Z Axis).](image)

| Cooling water temperature | Directional Deformation | Slope error RMS |
|---------------------------|-------------------------|----------------|
| 30°C                      | (-23,6) μm              | 70μrad         |
| 20°C                      | (-10,2) μm              | 45μrad         |
| 10°C                      | (-4,4) μm               | 20μrad         |

4. Conclusion
The cooling method for the collimation mirror has been used for several mirrors at the SSRF and they have been working well since May, 2009. And the infrared mirror is under fabrication at present.

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