ISBN: 978-3-95450-250-9 ISSN: 2673-5520 doi:10.18429/JACoW-MEDSI2023-THPPP007

# OPTIMIZING INDIRECT COOLING OF A HIGH ACCURACY SURFACE PLANE MIRROR IN PLANE-GRATING MONOCHROMATOR*

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*Abstract*

For the cooling of the plane mirror in VIA-PGMs (variable-included-angle plane-grating monochromators), the top-side indirect cooling based on water is preferred for its advantages, such as cheaper, easier to use, smart notches, etc, when compared to the internal cooling. But it also arises challenges to control the RMS residual slope error of the mirror, whose requirement is less than 100 nrad. This requirement is even hard to fulfill, when combined with 1) the asymmetry thermal deformation on the meridian of the footprint area during the energy scanning, 2) the high heat load deduced by the synchrotron light and 3) the no obvious effects of the classical optimizations, such as increasing footprint size, cooling efficiency or adding smart notches. An effective way was found after numerous attempts, which is to make the footprint area far from the mirror's edge to reduce the asymmetry of the thermal deformation except for leading to a longer mirror. This paper will illustrate how the asymmetry affects the mirror's residual slope error and then, focus on the relationship among the asymmetry of cooling and the distance to provide a reference for optical cooling.

## INTRODUCTION

In recent years, numerous light sources are developing synchrotron facilities with higher brightness, smaller divergence angle and more stability. During the development, the researching of the optics cooling of the beamline has draw much attention for the crucial role to realize these goals. There are so many articles focus on the cooling art of the first mirror because it bears the highest heat load among all the optics in a beamline [1-5]. However, for some VIA-PGMs in the downstream of the first mirror, few report about the cooling of optics in the PGM was found. And the cooling of the VIA-PGM had become an issue in some synchrotron facilities with high brightness and ultra small divergence angle, not only for its thermal working condition and high accuracy surface requirement of the mirror but also for its different optimization of cooling, compared to first mirror. This article will briefly list the common optimizations for the cooling of first mirror as references; then, based on a high heat load mirror of a beamline of Hefei Advanced Light Facility (HALF) [6], the limitation of these optimization are introduced; and at last, the reason and resolution are provided.

* This work is supported by the Chinese Academy of Science (CAS) and the Anhui province government for key techniques R&D of Hefei Advanced Light Facility.
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## OPTIMIZATIONS FOR INDIRECT COOLING OF THE FIRST MIRROR

For water cooling solutions, indirect cooling technology is still the first choice in design, when considering drawback of the internal cooling optical components, such as the long supply period, expensive, difficult to maintain, etc. [7]. Further, the indirect cooling has the capacity to utilize the reverse thermal moment, local heat compensation, etc to improve the slope error of thermal deformation. This part briefly introduces the common optimization method of the first mirror cooling of the beamline.

From 1996, Khounsary et al. adjusted the width of the cooling area and the bias and the depth of the notches on the side of the first deflection mirror to change the temperature distribution, which diminished the meridian slope error of the central part of the footprint (Fig. 1(a)) [1, 7, 8]. The principle of the two method are same. The bending of the mirror can be substantially reduced or reversed by a reverse thermal moment generated from the temperature difference between different uniform temperature region. And the notch has a more obvious effect because it makes the temperature difference between the uniform temperature region larger, and thus the expands the balanced thermal moment.

From 2013, Zhang Lin et al. reported the method on cooling length tuning to optimize the edge effect of the first mirror and upgrade it via heaters, as shown in Fig. 1(b) [4, 9]. At the two ends of the spot area, the heat flow reduced and became zero out of the area. This sharp change in heat flow leaded to a large slope error in these area, which named the edge effect on meridian. The effect also affected the inner zone of the spot area except for the edge area. Zhang's method made the cooling length shorter than the spot length, which can rise the temperature of the two end locations, to compensate the effect.

In 2016, Corey Hardin et al. reported a cooling method based on liquid metal bath and surface shape tuning technique for horizontal deflection mirrors. This method decoupled the effect of fluid induced vibration to optical components during cooling. As Fig. 1(c), although the optical element used unilateral cooling, the structure of the mirror still retains a symmetrical design [10].

In 2022, Wang Shaofeng and Gao Lidan et al. illustrated another cooling method for horizontal deflection mirror. Different from the design of Corey Hardin, this is a structure of unilateral cooling, notches and asymmetry to simplify the processing and assembly, as in Fig. 1(d) [11].

Beyond the mentioned above, the slope error of thermal deformation can also be decreased by improving the cool-

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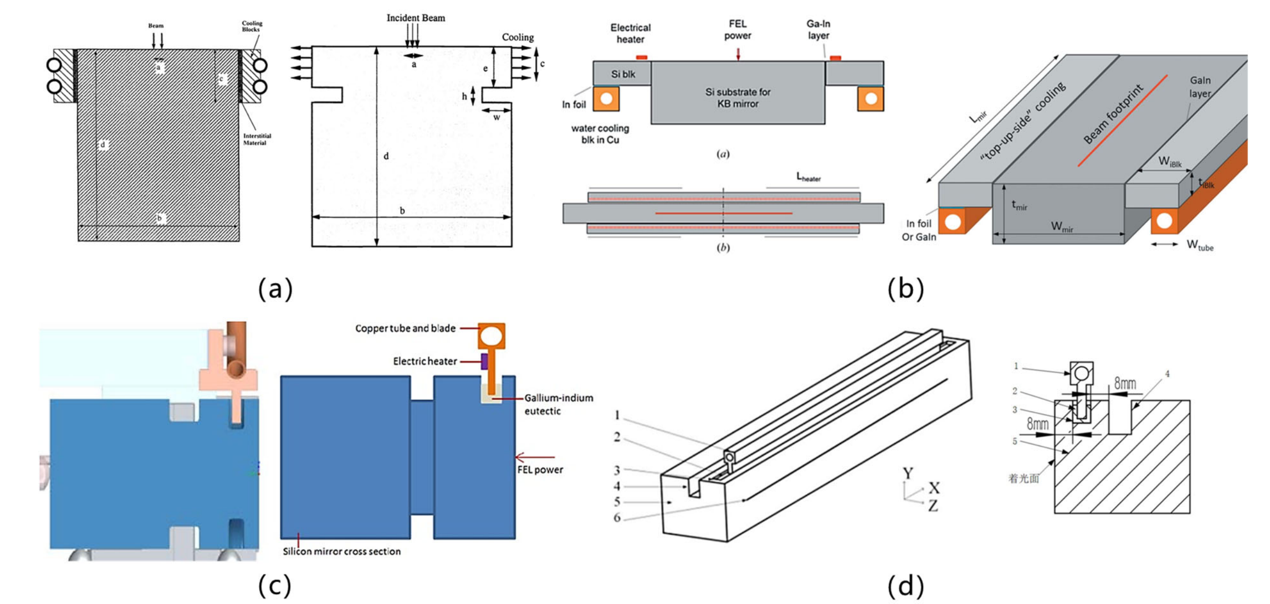
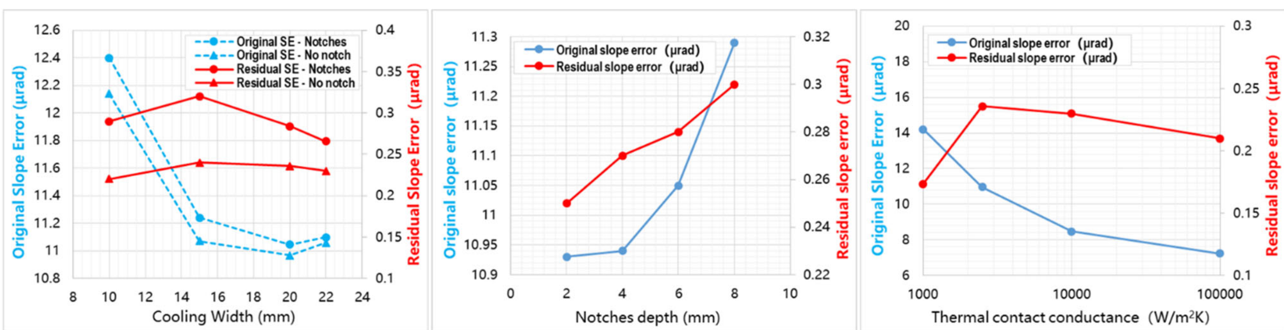



Figure 1: The optimizations for the first mirror of beamline.




a) Influence of the cooling width and notches bias. ( TCC = 2500W/m²K)

b) Influence of the notches' depth. ( TCC = 2500W/m²K)

c) Influence of the contact thermal conductance. (No notch, Cooling width: 20mm)

Figure 2: Optimizations effects on the residual slope error in the meridian direction (Film coefficient = 3600 W/m$^2$K , *Thermal contact conductance, TCC ).

ing efficiency via In-Ga which can reduce the defomation generated by clamp force [7, 12].

## LIMITATIONS OF THESE OPTIMIZATIONS FOR PLANE MIRROR

The optimizing methods mentioned in section 2 focused on the first mirror of beamline, whose spot area featured with 1) the symmetry center of the heat load distribution coincides with the symmetry center of the cooling structure of the optical element in the meridian direction; 2) the length of the spot area are as long as the mirror; 3) the power density on the spot area are almost uniform in the meridian direction [7, 13]. However, for the plane mirror in the VIA-PGM (variable-included-angle plane-grating monochromators), the spot size on it are very short than the mirror and the spot's location are vary with the output energy of the PGM. Figure 3 pictured a plane mirror's 6σ power density of a beamline's PGM in HALF under the maximum heat load working condition. The meridian slope error of the 4σ area should be smaller than 200 nrad.

These optimizations mentioned were implemented and the corresponding results are shown in Fig. 2. From Figs. 2 (a) and (b), the limited improvement of the two methods can be witnessed, none of them can push the residual slope error down to 200 nrad. Figure 2(c) also tells a slight changing about thermal contact conductance, except for the 1000 W/m$^2$K condition whose margin is not enough and temperature rises to 71 ℃. The heat flow compensation cooling method is relative complex so that not discuss conducted here.

## RESOLUTIONS FOR COOLING OF PLANE MIRROR

A core reason, that can be put after comparing the curve of deformation and fitted one ,is the asymmetry of thermal deformation in the meridian direction, which dues to the asymmetry cooling structure. This problem will become even worse under the maximum heat load working condition. The effective way to handle it is make the high heat load spot far from the edge of the plane mirror. Via parametric simulation, the balanced parameter can be easy found via curves shown in Fig. 4.

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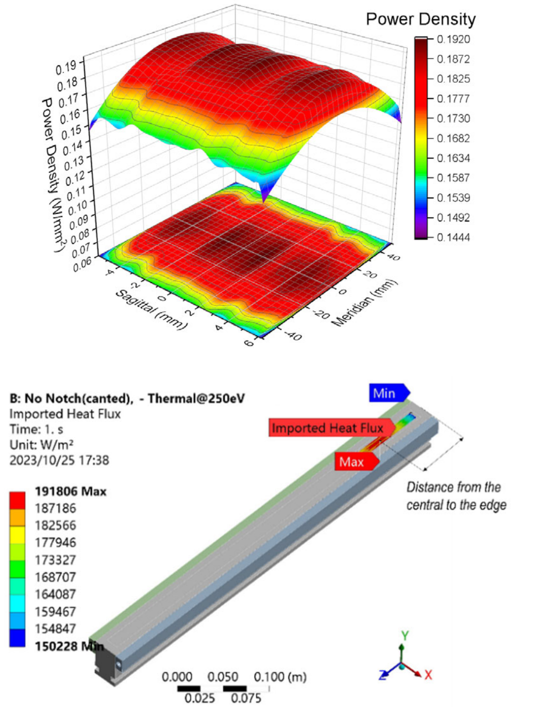


Figure 3: Power density under the maximum working condition ($q''_{max}$=0.192 W/mm$^2$K, P = 188.5 W) and the cooling structure utilized.

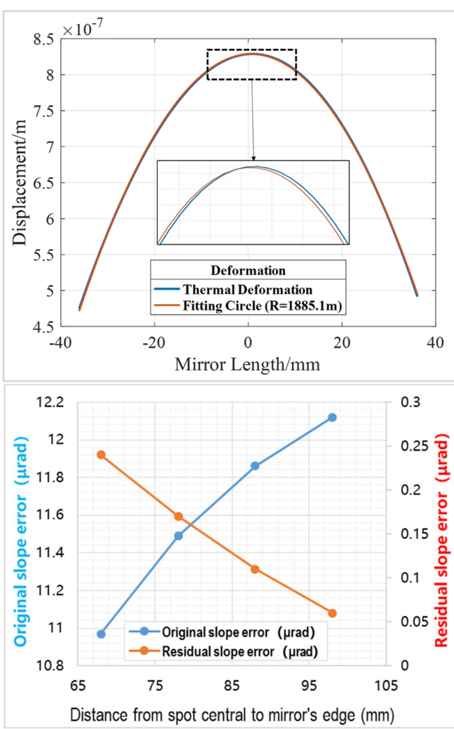


Figure 4: Distance effects on the residual slope error.

## CONCLUSIONS

Careful considerations of the cooling of the plane mirror are demanded, whose optimizations are different from the first deflection mirror. In this part, design and analysis of a high heat load plane mirror's cooling of VIA-PGM were described. Combined with the optimizations targeted to the first mirror and symmetry improvement of the PM's cooling structure, the monochromator is expected to provide the required performance for heat load of up to 0.192 W/mm$^2$, 188.5 W on the mirror at the max heat load condition. But it is suitable for these monochromator who has a relative large space to do the implement.

## ACKNOWLEDGMENTS

We wish to thank Gao Lidan, Jin Limin and Xu Zhongmin for their assistance and fruitful discussions.

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