THERMAL ANALYSIS OF HIGH HEAT LOAD MIRRORS FOR THE IN-SITU NANOPROBE BEAMLINE

MEDSI PARIS 2018
MECHANICAL ENGINEERING DESIGN OF SYNCHROTRON RADIATION EQUIPMENT AND INSTRUMENTATION
25-29 JUNE
SOLEIL SYNCHROTRON

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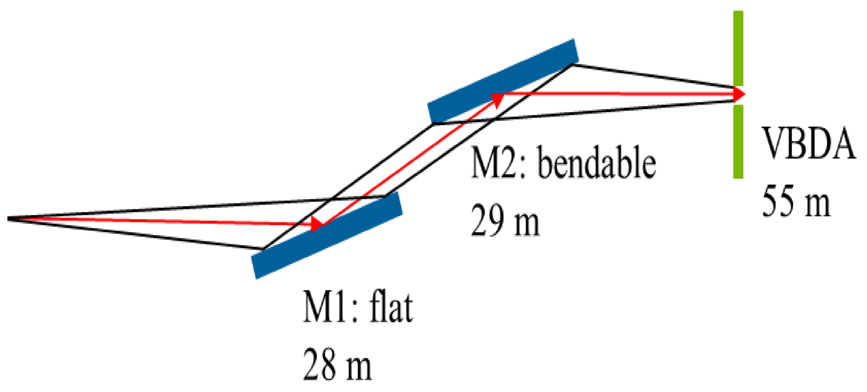
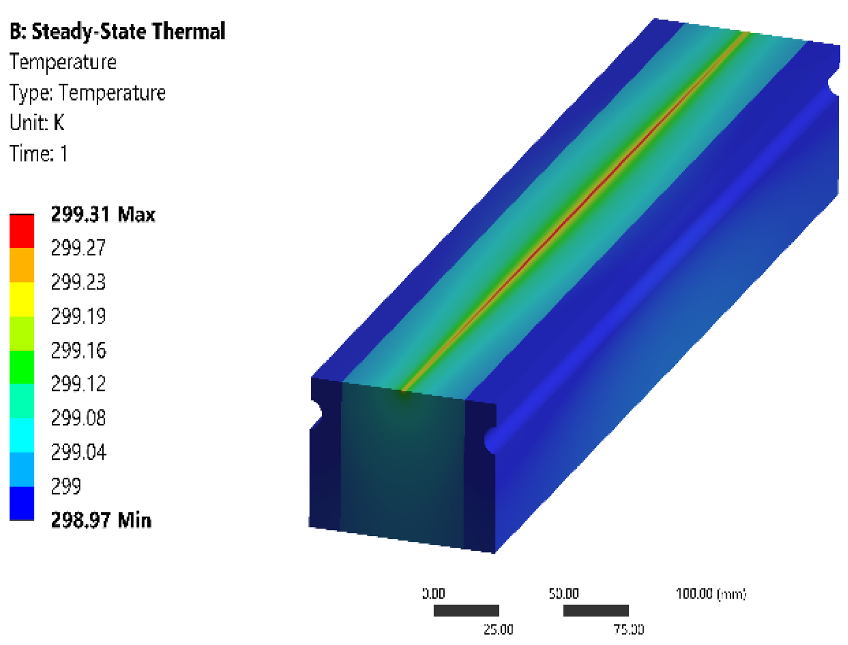
ABSTRACT

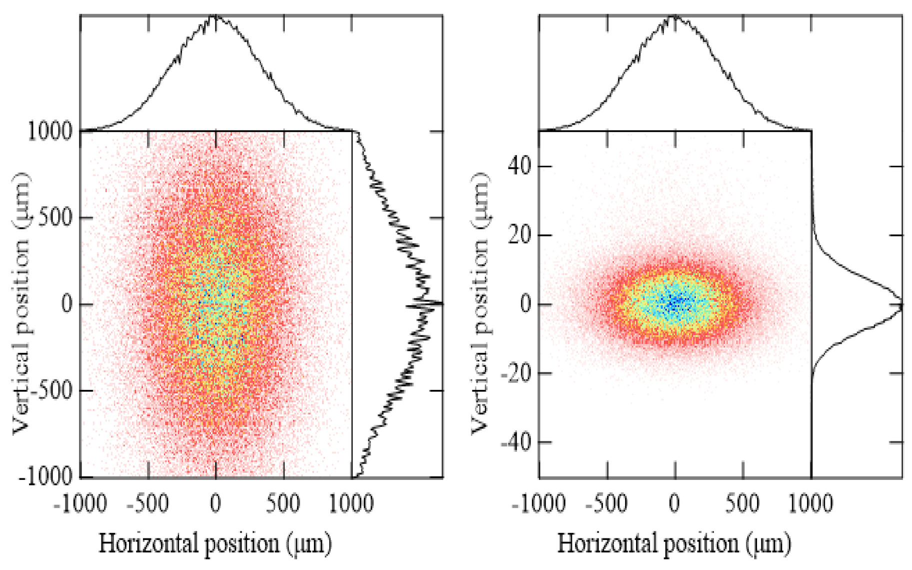
The Advanced Photon Source is currently in the process of upgrading to a multi-bend achromat storage ring, which will increase brightness and coherent flux by several orders of magnitude. The planned In-Situ Nanoprobe beamline, one of the feature beamlines of the APS Upgrade project, is a 220 m long beamline that aims to focus the x-ray beam to a spot size of 20 nm or below. In this beamline, a double-mirror system containing a high heat load mirror and a pink beam mirror is designed to provide high harmonic rejection and focus the beam to a beam-defining aperture (BDA). One of the key issues is to manage the high power and power density absorbed by these mirrors due to the new source. To attain the best focus at the BDA, the pink beam mirror needs to be mechanically bent to correct for thermal deformations on both mirrors. In this study we report on the thermal responses to different cooling schemes (e.g., side and internally water cooled) for these mirrors as calculated with Finite Element Analysis and optical ray tracing.

THERMAL ANALYSIS

- Finite Element Analysis was used to calculate thermal deformation on the surfaces of the M1 and M2 mirrors.
- Heat loads from the incident beam were calculated by SRCalc for silicon mirrors. Both mirrors are assumed to be side cooled with OHFC copper cooling blocks. Heat loads were mapped between 5 keV and 12 keV at 1000 eV increments.
- Thermal contact resistance between the silicon and copper was designated to be 8000 W/m² [1].
- Resultant thermal deformations were used to calculate the focal spot size at the BDA. From the focal spot size the bending radius required to achieve focus was calculated.
- The maximum increase in focal spot size (FWHM) after bending when compared to a theoretical mirror without a thermal bump is only 0.2 microns.







ENERGY SCAN

- The ISN beamline will likely scan energies for some studies. Analysis was done to determine the change in focal spot size at the BDA when scanning energies.
- The scanning range looked at was between 5.0 and 5.1 keV. The bend of the M2 was held constant at 4.38 km which is optimized for 5 keV.

Photon energy	5 keV	5.1 keV (no correction on M2)
K_y for undulator U25	1.862	1.833
Total power absorbed by M1 (W)	429	418
Total power absorbed by M2 (W)	10.6	10.0
Focal size at BDA with R2 = 4.38 km optimized for 5 keV (µm), FWHM	16.8	21.0
Focal position relative to BDA (m)	0	-1.7

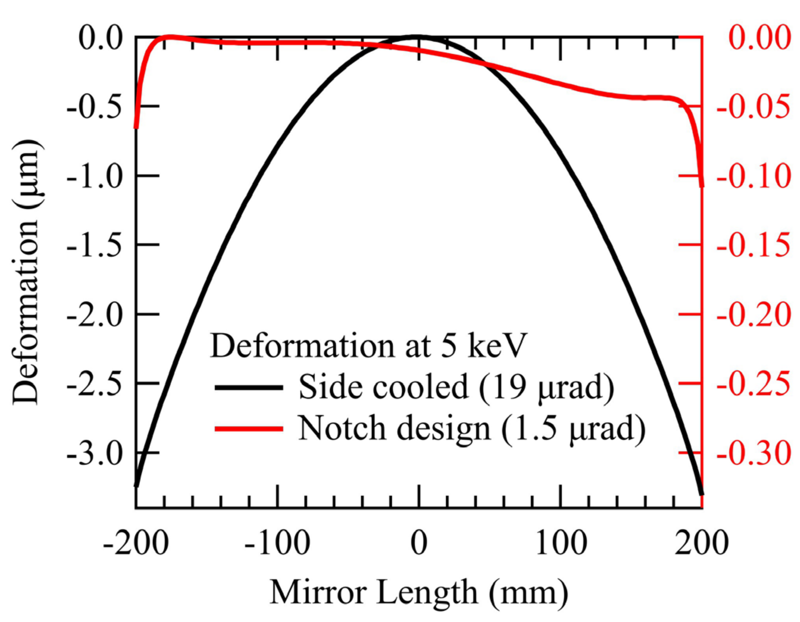
FOCAL SIZE COMPARISON

Photon Energy	5 keV	7 keV	9 keV	12 keV
Total Power absorbed by M1 (W)	429	260	130	20.3
Total Power absorbed by M2 (W)	10.6	9.06	6.23	5.79
Focal Size at BDA (µm), FWHM Theoretical	16.6	14.4	13.0	11.6
Focal Size at BDA (µm), FWHM Thermal Bump, No Correction	1129	589	257	47
Focal Size at BDA (µm), FWHM, Thermal Bump, Corrected	16.8	14.2	13.0	11.6
Corrected M2 Radius (km)	4.38	5.72	7.51	10.1
Corrected M2 Angle (degrees)	-1.4E-05	-9.0E-06	-5.0E-06	-1.1E-06

FURTHER OPTIMIZATION

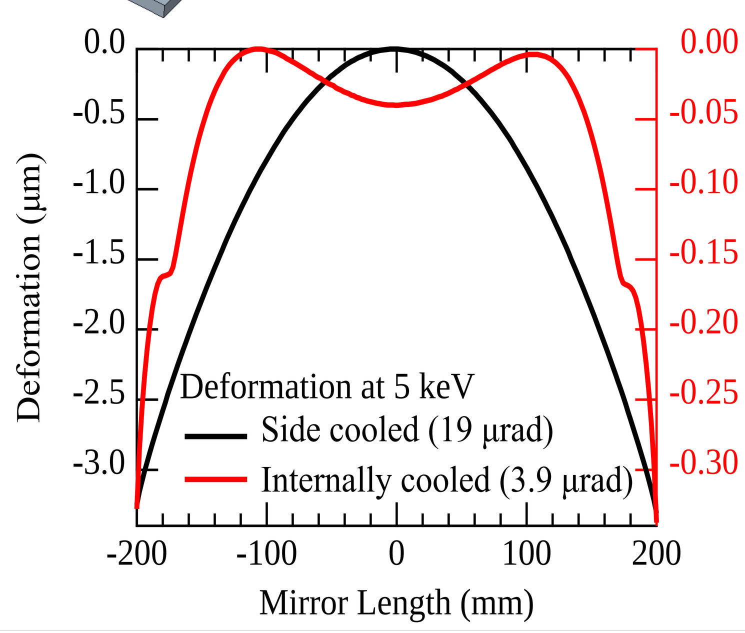
Notch Design

- It has been shown that slope errors can be reduced by an order of magnitude by adding a notch to the side and only applying cooling above the notch[2-3].
- A notch of 8 mm x 7.5 mm was determined to be the optimal size notch for 5 keV.
- Analysis conducted with this notch size on the M1 mirror produced such a flat thermal bump that the focal spot size increased by only 0.2 microns.
- The small increase in focal size could potentially eliminate the need for bending the M2 Mirror.



Internally Cooled

- Recent improvements in internally cooled mirrors also make them a viable option to reduce slope errors compared to side cooled mirrors [4].
- Analysis was conducted on an internally cooled mirror with seven channels placed 1 mm below the optical surface that are 1 mm wide by 6 mm high.
- FEA results show that an order of magnitude reduction in slope error is possible as compared to side cooled mirrors. Unfortunately, the slope error is a shape that is not correctable by the M2 mirror.



CONCLUSIONS

Based on the modeling, a focal size very close to the theoretical beam size one obtains without thermal distortions can be achieved by bending the M2 Mirror. This approach will allow the end station of the ISN Beamline to be able to achieve focal sizes of 20 nm or less. Preliminary results show that the notch and internally cooled mirror designs will greatly reduce the beam distortion due to thermal deformation. While these calculations show promise for reducing slope errors by an order or magnitude or greater, empirical studies need to be conducted to confirm these results.

REFERENCES

[1] A. Khounsary, D. Chojnowski, L. Assoufid, and W. Worek, “Thermal contact resistance across a copper-silicon interface” *(SPIE ’97)*
[2]L. Zhang, *et al*. “Thermal distortion minimization by geometry optimization for water-cooled white beam mirror or multilayer optics” *(SRI 2012)*
[3]A. Khounsary., “Thermal Management of Next-Generation Contact-Cooled Synchrotron X-Ray Mirrors” *SPIE annual meeting*
[4] A. Khounsary, “Design, fabrication, and evaluation of an internally cooled silicon carbide mirror”

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Argonne National Laboratory is a U.S. Department of Energy laboratory managed by UChicago Argonne, LLC.

* Work at the Advanced Photon Source is supported by the U. S. Department of Energy, Office of Science, Office of Basic Energy Sciences, under Contract No. DE-AC02-06CH11357.

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