THERMAL ANALYSIS SOFTWARE FOR OPTICAL ELEMENTS OF HEFEI ADVANCED LIGHT FACILITY*

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Abstract

Thermal deformation is a key influencing factor in the surface shape of optical elements for beamline. In the process of beamline design, it is necessary not only to select different cooling schemes based on thermal loading conditions but also to extensively optimize the parameters of these cooling schemes. The traditional approach for optimizing cooling scheme design often requires significant manual effort. By integrating existing experience in optimizing cooling scheme designs, this study transforms the parameterized design tasks that are originally performed manually into automated processes using software. This paper presents the latest advancements in the automated design software for cooling schemes of beamline optical components, and the results indicate that the optimization outcomes of the existing automated design software are close to those achieved through manual optimization.

INTRODUCTION

ANSYS-based thermal analysis methodologies have found extensive application in the design of cooling strategies for optical elements employed in synchrotron radiation light sources worldwide. As the development of synchrotron radiation light sources progresses, the thermal analysis of optical elements faces two key challenges: (1) A notable increase in the quantity of high heat load optical elements, imposing a substantial burden on the engineering optimization phase of cooling system design, often demanding significant efforts from designers. (2) The need for optical elements to conform to exacting standards regarding the non-destructive transmission of radiation from the light source to the end-station, which significantly complicates the engineering optimization of cooling schemes, often necessitating iterative refinement.

Cooling methods for synchrotron optics are generally well-established, encompassing techniques such as direct cooling, indirect side cooling, and indirect liquid metal cooling [1-3]. At the Hefei Advanced Light Facility (HALF), the predominant cooling methods include direct cooling, indirect side cooling, and indirect liquid metal cooling. Within HALF, principal cooling mechanisms involve side water cooling, liquid metal bath water cooling, and side liquid nitrogen cooling. While these cooling schemes possess relatively fixed spatial structures, variations in parameters, such as the positioning and depth of Smart cut, can substantially impact the geometry of optical elements. Consequently, the optimization of structural parameters assumes paramount importance in cooling scheme design.

To address this challenge, we have leveraged ANSYS secondary development technology [4-5] with the aim of crafting software tailored for the thermal analysis of synchrotron optics, thereby enhancing the efficiency of cooling scheme design.

SOFTWARE DESIGN

Solving Process

There are two routes for secondary development based on ANSYS: one is based on the secondary development of UPF inside ANSYS; the other is through MATLAB or python software, calling the command flow and ANSYS to solve the problem, and then return the results of the solution to MATLAB and python for further processing. We finally chose the second route for two reasons: firstly, we need to calculate the residual surface shape error and other information after obtaining the surface shape data, which is more conducive to data processing and visualization in MATLAB or python; secondly, we hope that in the future, the software can communicate with the optical calculation software, so as to obtain a more comprehensive beamline design software.

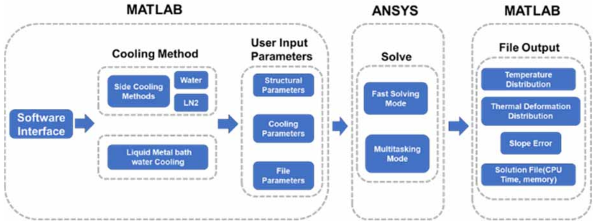

Figure 1: Computational route of the software.

The software gives priority to the service of Hefei Advanced Light Source, so the functions developed for the time being include: side cooling method (water cooling, liquid nitrogen) and liquid metal bath water cooling method. Software operation process is as follows: first of all, in the MATLAB interface to select the cooling program, and input structural parameters, cooling parameters and file location information; the parameters are processed and then written into the command flow file, and then call ANSYS to read the command flow file for the solution, after the completion of the solution, the output of the results of the file, such as the distribution of the surface type, the temperature distribution, as well as the solution of the information (such as solving time, consume memory, etc.), and finally MATLAB is used for data processing and

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visualization for easy reading. The computational route is shown in Fig. 1.

SOFTERWARE EXAMPLE

In this section, the focus is on the side cooling method in the software and its optimization example for plane mirror in test beamline in the Hefei Advanced Light Facility.

Model

For side cooling model, the optics are held on both sides by perforated copper blocks with an indium film sandwiched between the optics and the blocks to increase heat transfer. The model is shown in Fig. 2.

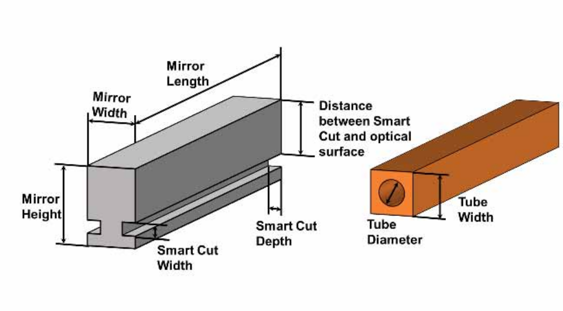


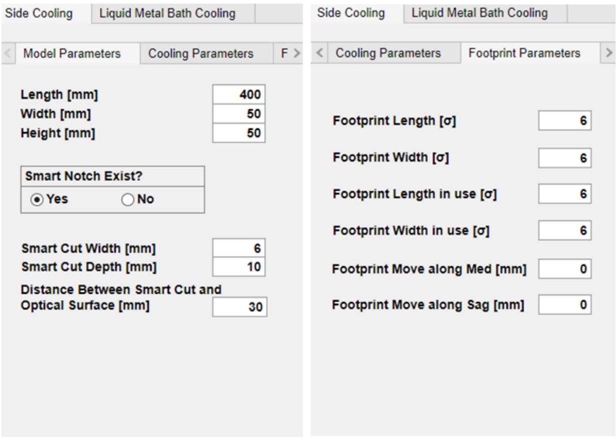
Figure 2: Model of side cooling method.

The factors affecting thermal deformation in the side cooling scheme are also all listed in Fig. 2. These parameters need to be set by the user in the software.

In the simulation, the indium film model is not established, but contact thermal conductivity of 12000 W/m^2/K is used to replace it [6].

Software Interface

In the software, in addition to the parameters in the previous section, it is also possible to set the footprint size to be used, which corresponds to the realistic situation of setting the slit downstream of the beamline as shown in Fig. 3. If the spot size used is too small, it will reduce the slope error but will also reduce the flux.



Length [mm] 400
Width [mm] 50
Height [mm] 50

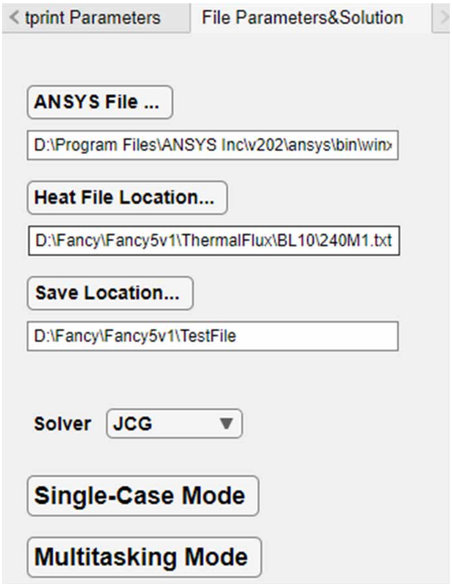
Smart Notch Exist?
● Yes ○ No

Smart Cut Width [mm] 6
Smart Cut Depth [mm] 10
Distance Between Smart Cut and Optical Surface [mm] 30

Footprint Length [σ] 6
Footprint Width [σ] 6
Footprint Length in use [σ] 6
Footprint Width in use [σ] 6
Footprint Move along Med [mm] 0
Footprint Move along Sag [mm] 0

Figure 3: Model parameters interface.

The shift in the footprint meridional direction corresponds to the spot shift due to the off-axis rotation of the optics. The shift in the sagittal direction, on the other hand, is used to calculate whether the thermal deformation meets the design requirements when the optics are in service for a certain period of time by moving the optics to avoid areas of possible damage.



D:\Program Files\ANSYS Inc\v202\ansys\bin\win›
D:\Fancy\Fancy5v1\ThermalFlux\BL10\240M1.txt
D:\Fancy\Fancy5v1\TestFile

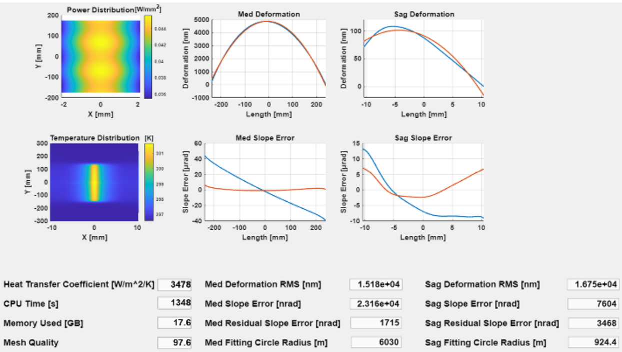
Solver JCG

Figure 4: File information interface.

Designers can use the multitasking mode in the software to analysis the effect of a parameter on thermal deformation by traversing it, and also to find the optimal solution as shown in Fig. 4. The multitasking mode allows traversing several parameters at the same time, which saves the designer's time.

The designer needs to select the location of the ANSYS .exe, the location of the heat load file, and the path to save the file in order to run the program correctly.

Designers can view the thermal deformation calculation results through the interface, in which the blue line represents the original thermal deformation and the red line represents the fitted circle as shown in Fig. 5. In the Slope Error curve, the blue line represents the original slope error and the red line represents the residual slope error.



Heat Transfer Coefficient [W/m^2/K] 3478
CPU Time [s] 1348
Memory Used [GB] 17.6
Mesh Quality 97.6
Med Deformation RMS [nm] 1.518e+04
Med Slope Error [nrad] 2.316e+04
Med Residual Slope Error [nrad] 1715
Med Fitting Circle Radius [m] 6030
Sag Deformation RMS [nm] 1.675e+04
Sag Slope Error [nrad] 7604
Sag Residual Slope Error [nrad] 3468
Sag Fitting Circle Radius [m] 924.4

Figure 5: Result interface.

Optimized Example

PM is the second mirror in test beamline with an absorbed total power of 64 W and power density of 0.2 W/m^2.

The optimization process allows us to study the effect of a particular parameter on thermal deformation as shown in Fig. 6. Figure 6(a) demonstrates the thermal deformation in the case of different smart cut depths, and Fig. 6(b) shows the relationship between the residual slope error in the meridional direction at the Smart cut depth.

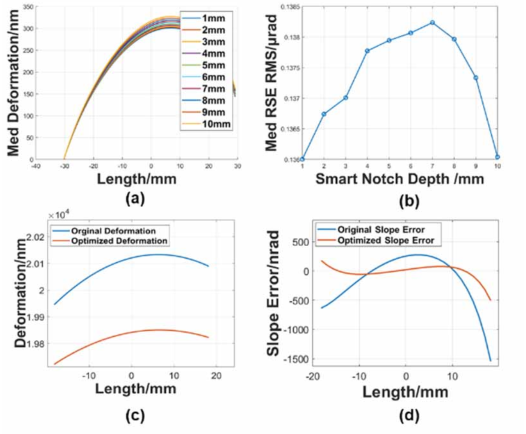


Figure 6: Optimized result.

After optimization of all parameters, Fig. 6(c) demonstrates the thermal deformation of PM before and after optimization, and Fig. 6(d) demonstrates the Slope Error of PM before and after optimization. Further information is shown in Table 1.

Table 1: Optimized Result

	Before	After
Sag Slope Error (μrad)	7.63	8.41
Sag Residual Slope Error (μrad)	0.09	0.08
Med Slope Error (μrad)	9.11	5.23
Med Residual Slope Error (μrad)	0.47	0.13

From Table 1, it can be seen that for the sagittal direction, the optimization effect is not obvious, while for the meridian direction the residual slope error is reduced from 0.47 μrad (rms) to 0.13 μrad (rms), which reaches the engineering requirement of 0.2 μrad (rms).

CONCLUSION

A thermal analysis software has been designed to optimize the design of the cooling structure and method of the optical components. The PM of the test beamline is used as an example to illustrate the cooling structure of the optical element. In the future, we will further optimize the design interface and improve the human-machine interaction.

REFERENCES

[1] L. Zhang *et al.*, "Thermal distortion minimization by geometry optimization for water-cooled white beam mirror or multilayer optics*". J. Phys. Conf. Ser.,* vol. 425, no. 5, p. 052029, 2013. `doi:10.1088/1742-6596/425/5/052029`

[2] L. Zhang *et al.*, "The performance of a cryogenically cooled monochromator for an in-vacuum undulator beamline", *J. Synchrotron Radiat.*, vol. 10, no. 4, pp. 313-319, 2003. `doi:10.1107/S0909049503012135`

[3] C. Cocco *et al.*, "Adaptive shape control of wavefront-preserving X-ray mirrors with active cooling and heating", *Opt. Express*, vol. 28, no. 13, pp. 19242-19254, 2020. `doi:10.1364/OE.394310`

[4] *ANSYS® ANSYS Mechanical APDL Command Reference*, ANSYS, Release 2020R2.

[5] *ANSYS® ANSYS Mechanical APDL Element Reference*, ANSYS, Release 2020R2.

[6] A.M. Khounsary *et al.*, "Measurement of thermal contact conductance of SPring-8 beamline components", in *Proc. SPIE,* vol. 6705, 2007. `doi:10.1117/12.735397`