Thermal Analysis for the Heat Distribution in Zerodur Disk Mirrors

NATIONAL ACCELERATOR LABORATORY

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Introduction

With the increased power and frequency of LCLS II, components in direct contact with the X-ray beam are more susceptible to thermal deformation. As a result, two analyses on Zerodur disk mirror were made to understand and map out the heat distribution. The goal of this project is to use one analysis to predict the laser damage testing results and the other analysis to predict how the heat distribution behaves with a cooling component.

Keywords: LCLS II, thermal deformation, heat distribution, ANSYS, mirror.

Background

According to Lin's SLAC Seminar in 2015, high temperatures and temperature variations can cause the disk mirrors to experience several thermal stress issues compromising the performance of the mirror. In order to model the disk failure, it is assumed that the temperature indicates failure.

Numerical Results

There are several ways to decrease the temperature of the disk without changing the material. Last year's intern, Jiya, worked on one method which is to use convection from water to cool the mirror. Through many calculations, he concluded a full side cooling would optimize the cooling. The following equations are Jiya's findings for a two-dimensional full-side cooling disk, which is then modeled in MATLAB:

$$\alpha_n R = \frac{hR}{k}\frac{J_0(\alpha_n R)}{J_1(\alpha_n R)}$$

Equation 1*: This equation describes the alpha constant (α_n) necessary to solve equation 2. I solved this using the symbolic toolbox and vpasolve function.

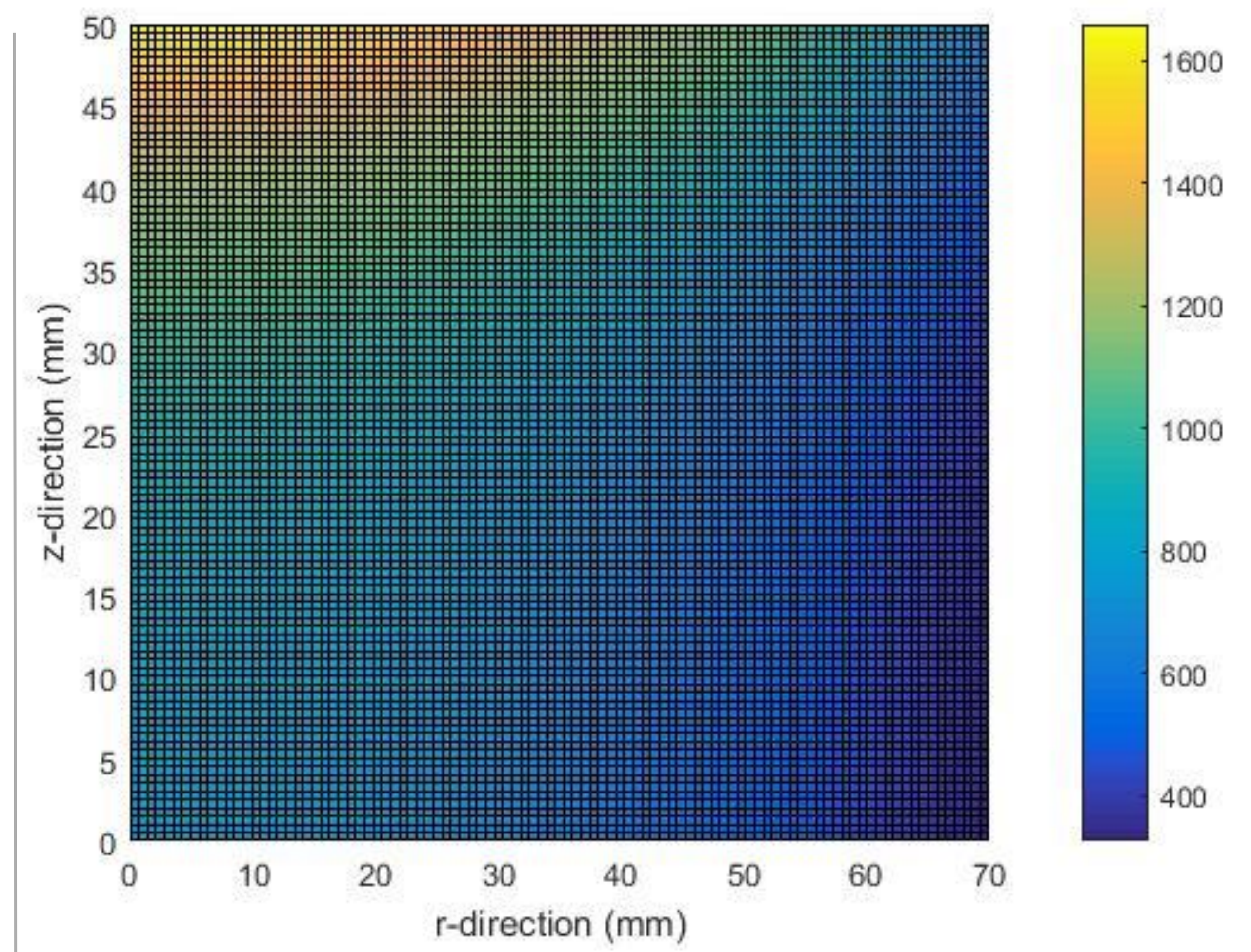

Figure 1: This MATLAB figure shows the thermal distribution of half the profile of the Zerodur disk.

$$T(r,z) = T_f + \sum_{n=1}^{\infty} \frac{P_a W_{bm}^2}{8kR}\frac{J_0(\alpha_n r)}{J_1(\alpha_n R)}\left[\frac{e^{-\alpha_n z} + e^{-\alpha_n (2H-z)}}{1 - e^{-2\alpha_n H}}\right]$$

Equation 2*: This bessel function describes the temperature change in two-dimensions, r (radius) and z (depth). P_a (beam power), W_{bm} (beam width), k (thermal conductivity), h (heat transfer coefficient), T_f (cooling temperature of fluid), R (radius of disk), and H (depth of disk) are constants in the equation. I used a for loop to calculate the summation.

Results with ANSYS

To analyze a three-dimensional object on ANSYS, a model is first created in a CAD software. For this project, I created two models on Solid Edge. The first is a disk the diameter of the x-ray beam. The second model is a donut-shaped disk the size of the disk being tested with a hole the size of the first disk. I mated the first disk into the second to create a disk, which is then ready to import into ANSYS. It was imperative to create a smaller disk because it created an area I could select for the heat flow of the beam in ANSYS.

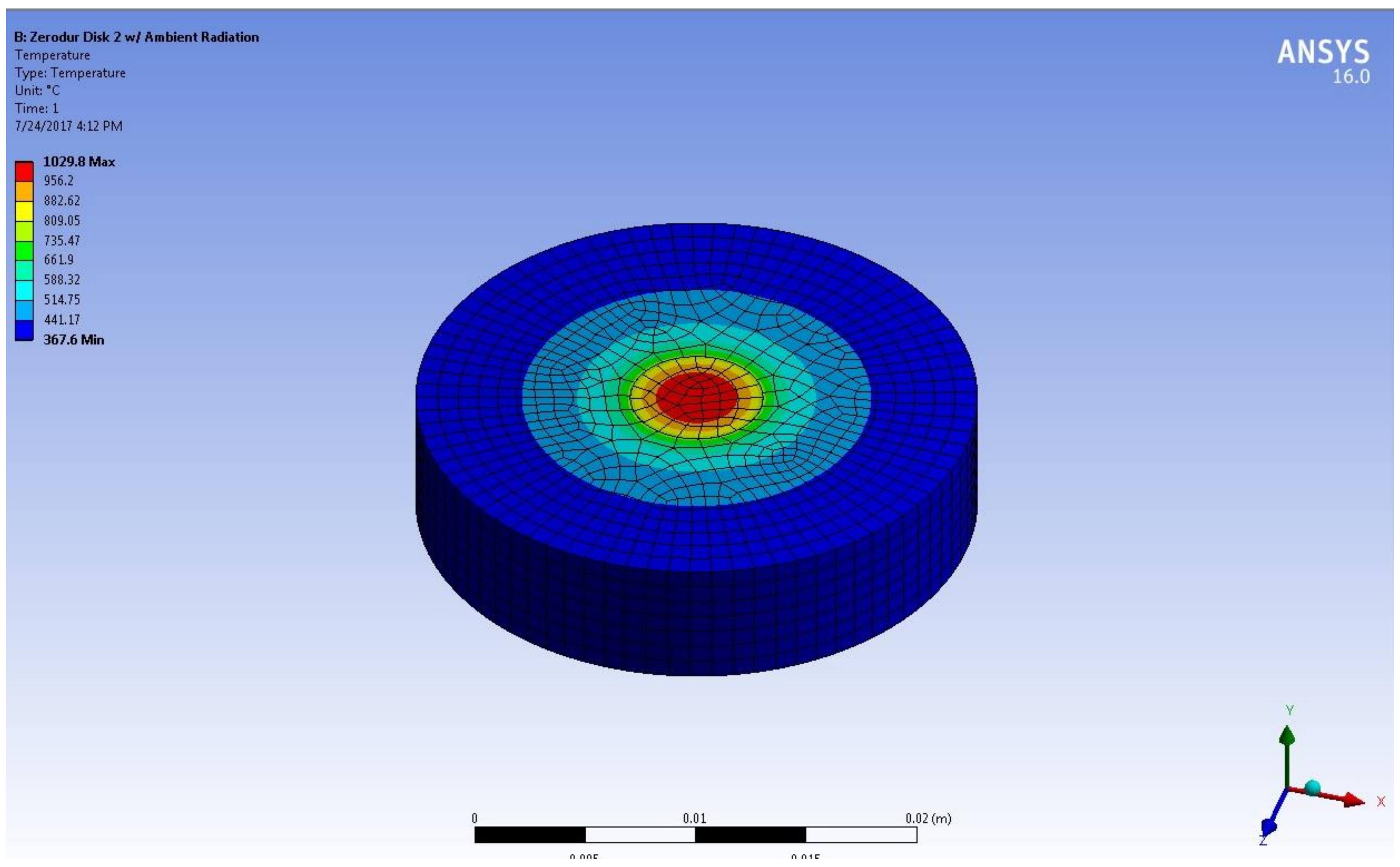

Figure 2: A steady-state thermal analysis with ANSYS makes it possible to map out the thermal footprint of the disk mirror. The purpose of the solution is to indicate the laser damage test team what we should expect from the laser damage laboratory tests.

Conclusions

For the analysis with ANSYS, I expected a large temperature range, however the maximum temperature was a much higher than anticipated. This is because the beam is described as a constant heat flow across the beam diameter. Realistically, the beam is described as a Gaussian distribution. Further work will include the Gaussian distribution as well as a transient thermal analysis.

For the analysis with MATLAB, the analysis was a challenge to model. Equation 1 had many solutions for α_n which altered Equation 2 to have oscillating characteristics. Through many alterations of the code, I found there is one true α_n solution that gives the expected heat distribution. The code is not perfect because the beam appears very wide and the maximum temperature is very high for a cooled disk.

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*Jiya Janowitz, SLAC Mathematical Proof, 2017
*Lin Zhang, SLAC Seminar, 2015

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