Ansys Steady-State Thermal Analysis of the Engineered Cooling Design for the Hall C Lead Tungstate Crystals of the Neutral Particle Spectrometer

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Two simplified models were created using Ansys software to simulate the temperature profile of the Hall C Neutral Particle Spectrometer (NPS) $PbWO_4$ crystal array, and to verify whether the engineered cooling design is adequate to maintain the temperature of the crystals at ~18°C ± 1°C for optimum efficiency. The results of the simulations are presented in this note.

NPS consists of 1080 $PbWO_4$ crystals, each connected to a Hamamatsu R41253355027 photomultiplier tube (PMT) that is connected to a divider base equipped with a low voltage amplifier. Between each crystal is a carbon fiber divider at the front and a mu-metal divider at the back, Fig. 1.

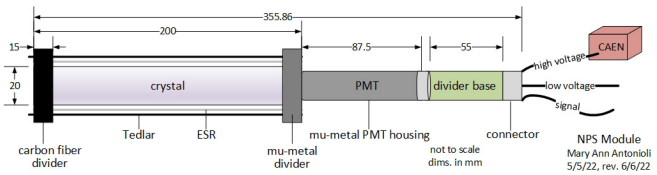

FIG. 1. Schematic of single NPS crystal module and power supply.

The crystals are surrounded by a copper cooling shell through which Kodiak chiller model number RC006G03BE3, Fig. 2 [1], flows water at 10°C.

FIG. 2. Lytron Kodiak chiller for crystal array.

The first model designed and simulated, using Ansys DesignModeler, consisted of nine crystals arranged in a 3 x 3 grid surrounded by a copper cooling shell. This model was then scaled up to a full-sized 36 x 30 crystal model.

The full-sized model with 1080 $PbWO_4$ crystals, carbon fiber dividers, and mu-metal dividers is shown in Fig. 3. The crystals are 200 mm x 20 mm x 20 mm. The carbon fiber dividers are 0.5 mm thick, 20 mm wide, and run the height and width of the crystal array; the mu-metal dividers 0.5 mm thick, 67.5 mm wide, and run the height and width of the crystal array. Since the dividers are between each crystal, there is 0.5 mm of air between each crystal. All of these components are wrapped with a copper cooling shell 165 mm wide and 12 mm thick.

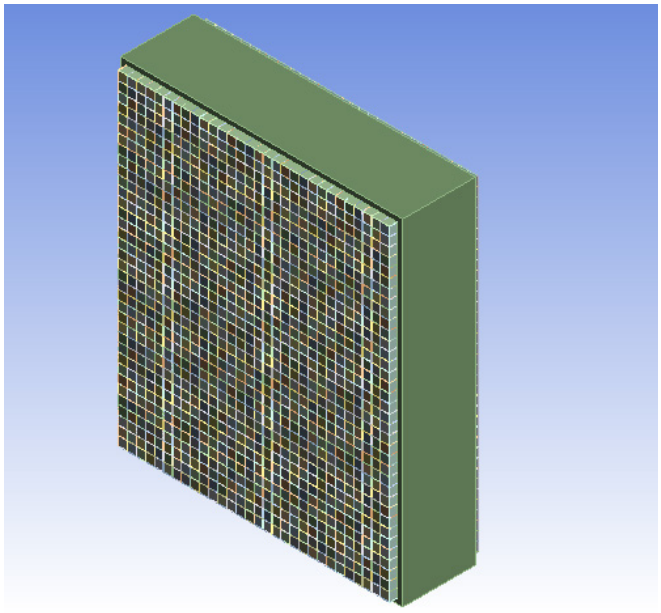

FIG. 3. Full-size model of crystal array with crystals, carbon fiber dividers, mu-metal dividers, and copper cooling shell.

The simulation parameters, Table I, were chosen such that each body of the model had a convection rate of 2.5 W/m·°C, the ambient temperature was set to 20°C, and the copper cooling shell was set to 10°C. A heat load of 0.5 W was applied to the rear face of each crystal based on an expected heat load of 540 W for the entire crystal array [2].

The simulation results provided the overall temperature of the crystal array. To determine the temperature profile of the crystal array, temperature probes were placed on the front and rear faces of all 1080 crystals—a total of 2160 temperature probes.

The temperature probe values were extracted from the Ansys simulation using the script get-results4.py, developed using IronPython, an open source implementation of the Python programming language that can be used in Ansys for simula-

tion control and automation. Get-results4.py iterated over each temperature probe and saved the value for each to a text file.

Component	Property	Value
$PbWO_4$ crystal	size	20 x2 x 2 cm
	thermal conductivity, *x*- and *y*-axis	2.4 W/m·K
	thermal conductivity, *z*-axis	2.0 W/m·K
Carbon fiber dividers	thermal conductivity	0.5523 W/m·°C
Mu-metal dividers	thermal conductivity	19 W/m·K
Copper cooling shell	temperature	10°C
ambient air	temperature	20°C

TALE I. Ansys Steady-State thermal simulation parameters.

The Python program parse-temps.py was developed to parse the data file, removing header information and leaving only temperature values, which could be used to generate plots showing the temperature profile of the crystal faces only. The temperature gradient from crystal to crystal was determined after parsing the data file from the Ansys simulation.

Results of the simulation showed the crystal array's temperature in the range of ~10°C to ~22°C, with the highest temperatures in the central region of the crystal array, Fig. 4.

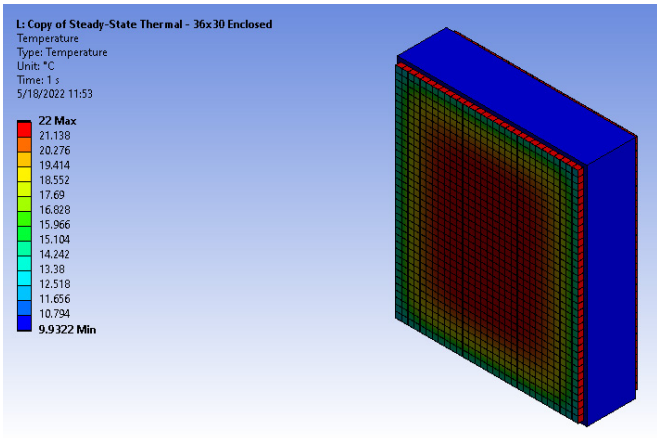

FIG. 4. Ansys Steady-State thermal simulation results.

The Python program ansysLego.py was developed to plot the front crystal face temperatures and provide a visual representation of the structure of the temperature profile. A three-dimensional rectangle representing each crystal was placed on a 36 x 30 grid. Each rectangle was assigned a color from blue to red, representing cooler to warmer temperatures. As can be seen in Fig. 5, the warmest temperatures (~22°C) are concentrated in the center of the crystal array and forms a plateau with the temperature sloping downward to the peripheral crystals with the coolest temperatures (~10°C)

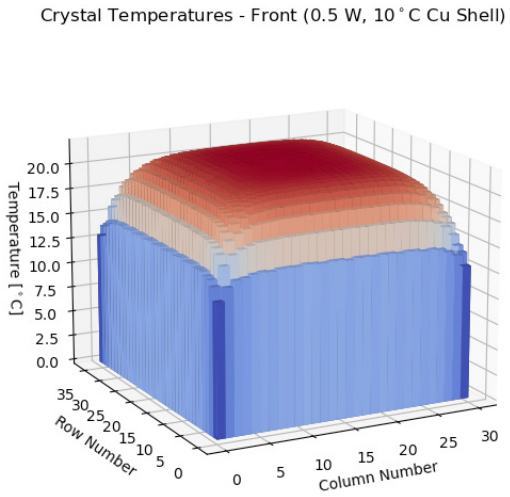

FIG. 5. Lego plot of front crystal face temperatures.

The Python program ansysHist.py was developed to plot a histogram, using temperature values for the front crystal faces and generating bins that are 1.5°C wide, Fig. 6. The bins were assigned a color from blue to red, representing cooler to warmer temperatures. The histogram shows that roughly 260 crystal face temperatures (~25% of the total) were close to the ambient temperature of 20°C.

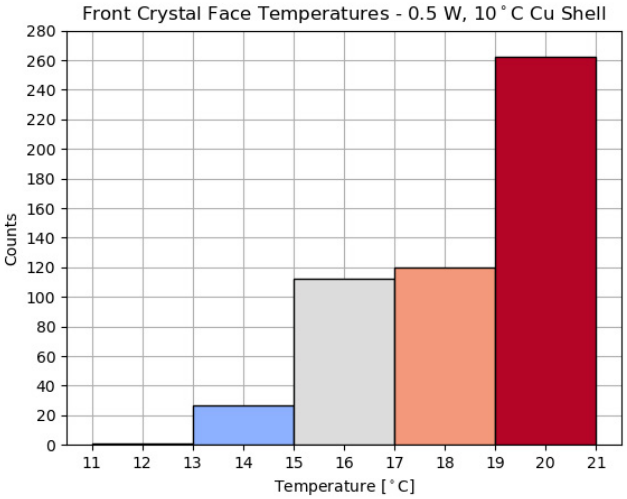

FIG. 6. Histogram plot of front crystal face temperatures.

To generate a streamline plot, the python program gradTest.py was developed, which took the temperature data and converted it to a 36 x 30 matrix. Then it called the Python numpy.gradient function, which, using the extracted temperature values as input, returned two matrices—one for temperature change in *x*-direction, and one for temperature change in the *y*-direction, creating a streamline plot. GradTest.py then plotted a 36 x 30 grid of squares to represent the front crystal faces. This grid was overlaid with the streamline plot, Fig. 7, showing that the heat flows from the central region, which is at ~22°C, to the periphery, which is at 10°C.

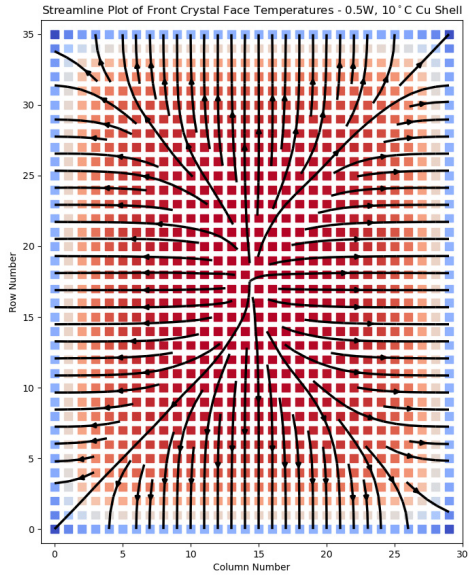

FIG. 7. Streamline plot of front crystal face temperatures.

Based on the simulations, it is clear that despite the engineered peripheral cooling design of the NPS, only 11% of the crystals are at 18°C ± 1°C. Additionally, it is noted that the temperature of the central crystals (~25% of the total) is determined by the ambient temperature.

[1] AAVID, Thermal Division of Boyd Corporation, *Kodiak Recirculating Chiller Technical Manual*, 2019.

[2] Carlos Munoz, *NPS Calorimeter Experimental Readiness Review*, presentation, 2019.