THERMAL ANALYSIS OF THE HIGH-POWER RACE TARGET

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The High-Power RACE (HP-RACE) Target, a component of the Reactor-Accelerator Coupling Experiments (RACE) Project, was designed to be coupled with a high-power electron linear accelerator (linac). The target is designed to be bombarded with electrons to produce photoneutrons via bremsstrahlung. This process will deposit up to 20 kW across a small mass of heavy metal, which requires an analysis of the targets thermal system to ensure a safe design. The design of the HPRACE Target's thermal system was initially done using mathematical models. The target was fabricated and assembled then low-power testing was performed at Idaho State University-Idaho Accelerator Center (ISU-IAC) using a linac that produced about one-twentieth of the designed operating power level. Experimental data obtained from these tests and theoretical calculations agree well at low power levels thus validating the procedures and mathematical models used in the design of the HP-RACE Target's thermal system. Fluent, a computational fluid dynamics code, was also utilized as an analysis tool. It was used to verify theoretical and experimental findings and to help identify any problem areas, such as hot spots caused by eddies, allowing any design issues to be addressed prior to high power testing.

I. INTRODUCTION

The design of the HP-RACE Target, which was completed as an award-winning Senior Mechanical Engineering design project at the University of Nevada, Las Vegas, is described in References 1 and 2. It is a component of the Reactor-Accelerator Coupling Experiments[3, 4] that were performed at the Idaho State University Idaho Accelerator Center (ISU-IAC) and the University of Texas (UT) at Austin. The HP-RACE Target was designed to be coupled with a ~20 kW electron linear accelerator (linac) producing 20-30 MeV electrons for photoneutron production. Bremsstrahlung radiation is produced as the incident electrons are quickly slowed in the heavy-metal tungsten target[5]. In the HP-RACE Target the electrons produced by the linac are focused over a small area at the center of a stack of tungsten disks separated by coolant channels. A substantial amount of the power supplied to the target is deposited in the disks. A thermal evaluation of the target's cooling system is necessary to ensure proper performance and prevent damage to the target or surrounding systems that it may be interfaced with.

II. COOLING SYSTEM DESIGN

The target disk stack consists of eight pairs of aluminum spacers whose shapes form coolant channels on the surfaces of the seven tungsten disks that separate them (Fig. 1). The tungsten disks increase in thickness from the front to the rear of the stack to allow for more even power deposition.

Figure 1. Partial tungsten disk stack assembly for the High-Power RACE Target held together with steel guide pins. The half-circle cut outs on the edges of the stack form the inlet and outlet supply lines once the assembly is inserted into the target body.

Four half inch water lines, two for inlet and two for outlet, supply and return coolant to and from the coolant channels. The water channels alternate flow direction. The first channel flows from the top left to the bottom right and the next channel flows from the top right to the bottom left. This design minimizes stagnant zones and vortices that might be created by flowing water into a single water channel from opposing directions[1, 2].

III. EXPERIMENTAL TESTS

At the time of testing, the 20 kW linac was not yet available so initial tests were performed at ISU-IAC with an accelerator capable of producing ~1kW (Fig. 2). Coolant was supplied to the target through two electrically isolated half-inch copper lines at about 1 L/min (0.22 gpm). Thermocouples were placed on the main inlet coolant line, main outlet coolant line and the body surface. Two testing sessions were completed, the first of which consisted of 389 and 583 W power levels. During the second session, beam power was varied to power levels of 100, 200, 300, 400, 500, and 640 W.

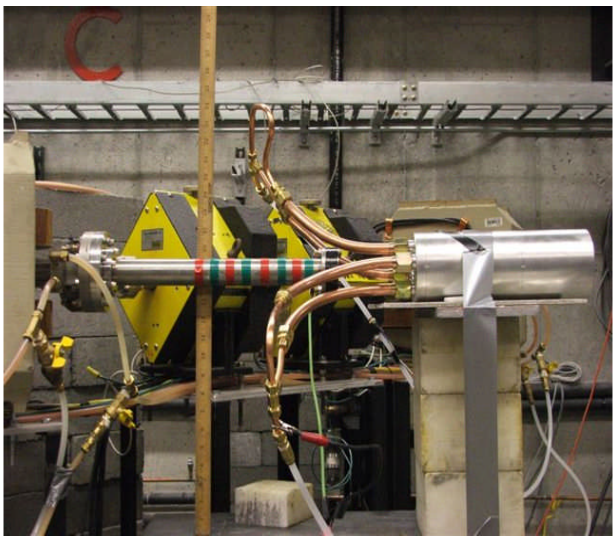

Figure 2. High-Power RACE Target, right side of picture, coupled with an electron linac entering from the left side of the picture and ending at the beam window located at the right end of the red and green stripes. The black and green wiring at the bottom center of the figure are grounds for electrical isolation.

IV. COMPUTER MODELING

Fluent[6], a computational fluid dynamics code, was used to verify results. The model built to be used in Fluent was designed to resemble the assumptions made in the design calculations. This was done because such a model is less complicated reducing computing power requirements and computing time. The model consisted of only the tungsten disk stack, with spacers, and coolant (Fig. 3). Building the model in this manner, results in conservative estimates of temperatures throughout the tungsten disk stack and coolant.

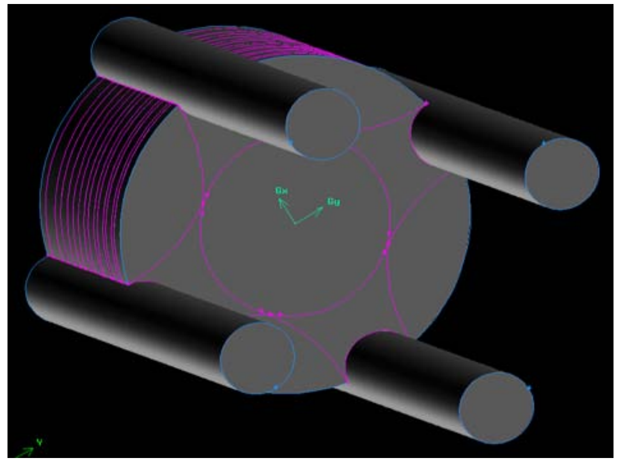

Figure 3. Completed model of the HP-RACE Target's assembled tungsten disk stack and coolant built and meshed in Gambit then imported into Fluent.

V. RESULTS

Experimental tests yielded results that were similar to those calculated. Figure 4 shows inlet, outlet and body temperature data plotted for the 389 Watt test. The difference between the experimental inlet and outlet temperatures is approximately 5° C. Design calculations for the same power level and coolant flow resulted in a temperature difference of approximately 7° C. The experimental results were expected to be lower than the calculations due to energy losses through the surface of the target in the first session of testing

Results obtained with Fluent are displayed in Figures 5 through 8. Figure 5 shows temperature contours on two slices taken along the axis of the target and through the main water inlets and outlets. The two coolant inlets are the darker blue legs with temperatures of 27° C (300 K). The two lighter blue legs are the coolant outlets and have average temperatures of approximately 34° C (307 K), resulting in an average temperature difference of 7° C. These are nearly the same results achieved in the design calculations.

Looking at the inlet and outlet temperatures of the coolant gives only an overview of the target's performance. The maximum amount of power that can be applied to the target is limited by the boiling point of the coolant, 116 °C at 40 psi since water is used. This means that the interface between the coolant and disk surfaces is the most important area to evaluate.

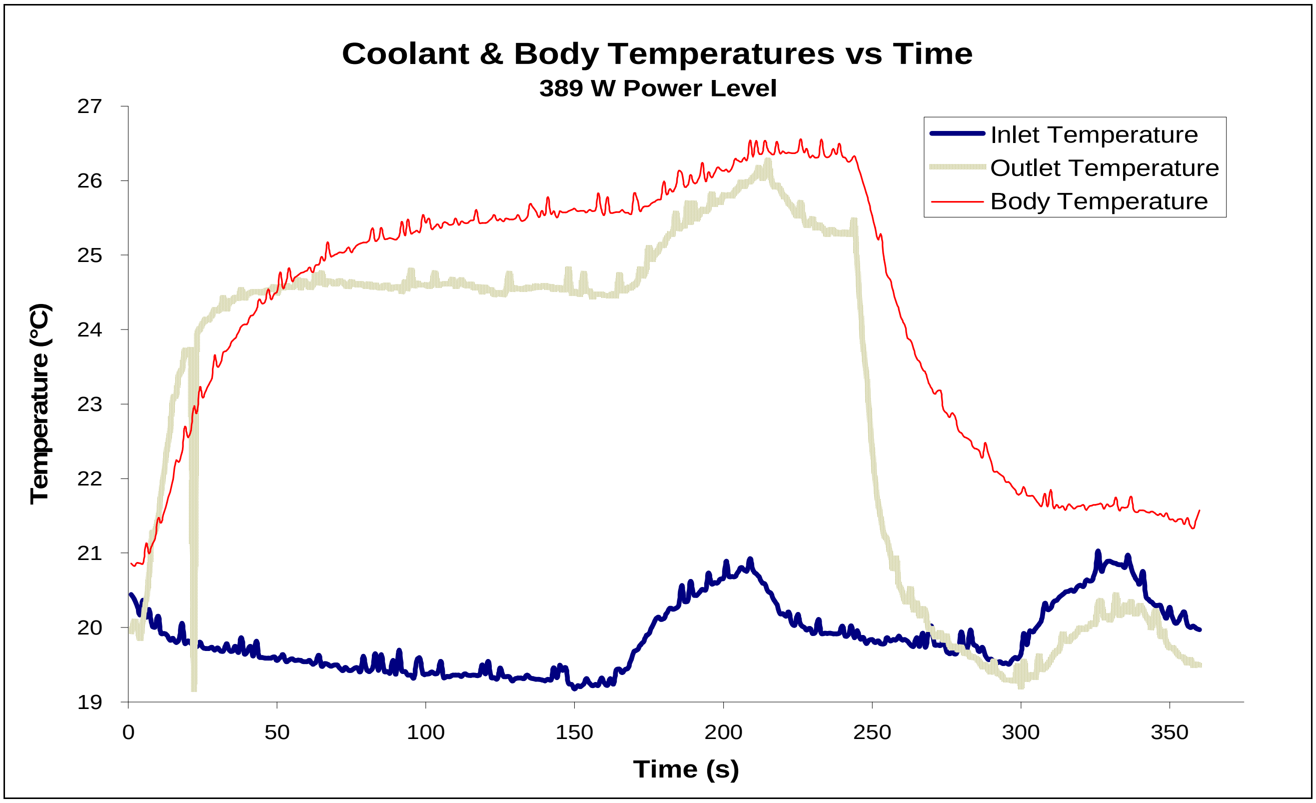

Figure 4. Coolant & Body Temperature vs Time for 389 W Power Level Test

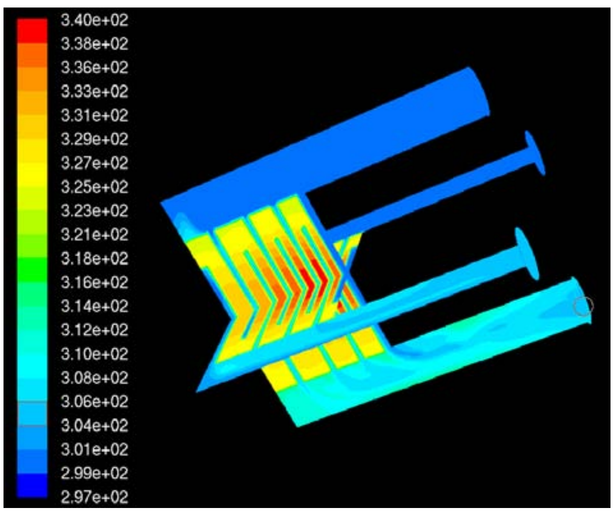

Figure 5. Slices taken axially through the HP-RACE Target's tungsten disk stack and cooling system showing temperature contours at 389 W of beam power.

Figures 6 & 7 are slices taken perpendicular to the axis of the target and show temperature contours 0.01 cm below the front and rear surfaces of the second tungsten disk, the disk with the greatest temperature increase. Temperatures range from 30° C to a max of 40° C. The average of this range agrees with design calculations that predicted average increases in disk surface temperatures to be approximately 36° C. There is no experimental data to compare these results to due to the lack of means available to acquire temperatures on the interior of the cooling system.

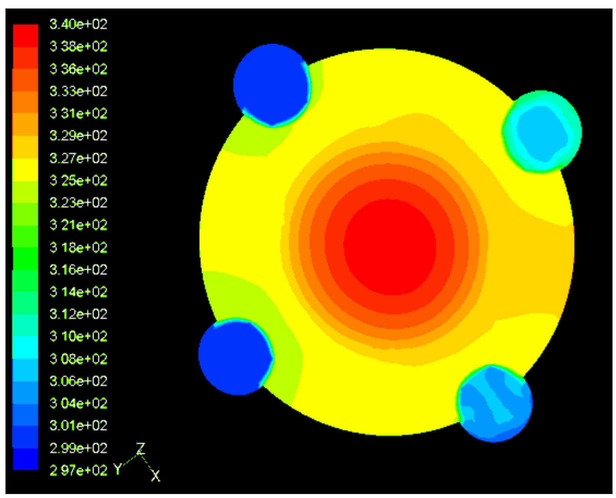

Figure 6. Temperature contours 0.01 cm below the front surface of the second tungsten disk of the HP-RACE Target with 389 W of beam power.

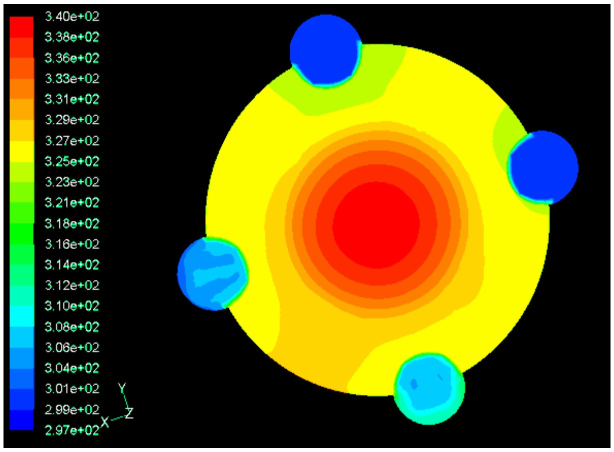

Figure 7. Temperature contours 0.01 cm below the rear surface of the second tungsten disk of the HP-RACE Target with 389 W of beam power.

VI. CONCLUSIONS

Theoretical calculations and experimental data correspond well at low power levels. This data cannot be accurately extrapolated to the design power of 20 kW, but the theories used to perform thermal calculations have been validated for this design. Using those theories and mathematical models with adjustments made for an increased coolant flow of 12 gpm, calculations suggest that the High-Power RACE Target is capable of accepting the application of a 20 kW electron beam.

As stated earlier, the limiting factor in the determination of the amount of power that can be dissipated by the target's thermal system is the disk surface temperatures. Since they are such a crucial element and Fluent results predicted slightly higher temperatures than design calculations, experimental results are necessary for comparison. Another concern worthy of noting is the flow of coolant through the channels, the restriction or blockage of which could have unattractive repercussions. Both of these concerns could be solved by implementation of a means to measure either the disk surface temperature or individual coolant channel flow.

More Fluent modeling is planned to gain a better understanding of how the target will react at higher powers and to give insight to any problem areas that may arise. A model representing the experimental tests has been created but has not been successfully run due to the computing requirements of such a complex geometry.

REFERENCES

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