Ansys Fluent Thermal Analysis of the Beamline Test Stand

Pablo Campero, Mary Ann Antonioli, Peter Bonneau, Aaron Brown, Brian Eng, George Jacobs, Mindy Leffel, Tyler Lemon, Marc McMullen, and Amrit Yegneswaran
Physics Division, Thomas Jefferson National Accelerator Facility, Newport News, VA 23606
August 30, 2023

This note presents the results of the computational fluid dynamics thermal analysis of the Electron Ion Collider (EIC) beampipe test stand, assembled to study the thermal interaction between the beryllium pipe and the first layer of the silicon tracking sensor. [1]. Results show the maximum temperature of the first silicon layer at a specific inlet airflow velocity through the space between the beampipe and the first silicon layer (annulus).

Initially, the test stand model only included the central section (silicon pipe, aerogel, beampipe and heater solid) [2]. The model was changed to include the actual lengths and additional components—the heater elements, the heater pipe, the beampipe, 1-mm aerogel insulator, inlet pipe with ¼ inch connectors, and the silicon pipe [3], Fig.1.

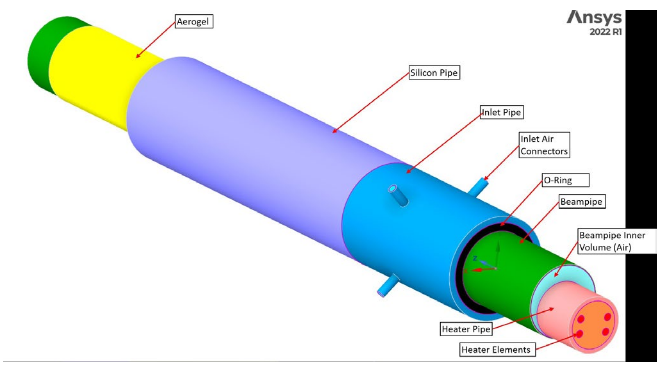

FIG.1. Isometric view of the test stand model.

The contact area between the outer and inner surfaces of the heater pipe and the beampipe was reduced to the minimum allowed in Ansys SpaceClaim software, Fig. 2.

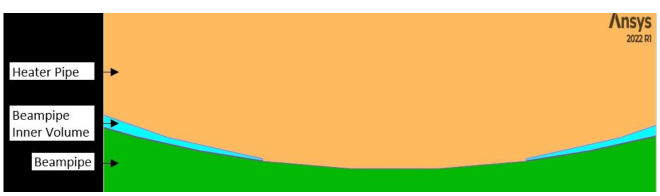

FIG 2. Close-up of the model at the heater pipe and beampipe contact area.

Table I shows the thermal properties of the solid components' materials.

For the fluid domains, air for the beampipe inner volume and mineral oil for the heater pipe inner volume were configured. Since the thermal properties vary as a function of the temperature for mineral oil, thermal properties were set by the values of the associated polynomial curves. Data to calculate the polynomial coefficients were based on their specifications [4]. Figure 3 shows how the specific heat of the mineral oil varies when the temperature changes.

Component	Material	Density [Kg/m3]	Specific heat [J/Kg°C]	Thermal conductivity [W/m*K]
Heater pipe, heater elements	steel	7850	420	45
Beampipe, silicon pipe, inlet pipe, ¼" air connectors	aluminum	2719	871	202.4
Insulator layer	aerogel	150	948	0.04
O-ring	rubber	1150	1050	0.2

TABLE I. Materials' thermal properties for solid components.

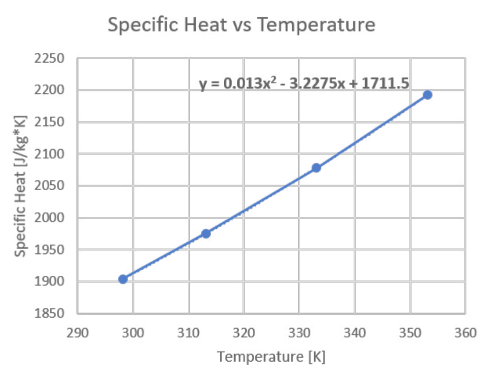

FIG 3. Specific heat vs temperature curve and associated polynomial.

For the model, cell zones and boundary conditions were created in Fluent. Two methods of generating the heat were considered—one by setting the heater elements with a fixed temperature and the other by setting the heater elements with power, based on its volume (W/m^3). For heat transfer, forced convection for the annulus where the air is input from each inlet connector and natural convection for the beampipe inner volume (air) and for the inner volume of the heater pipe (mineral oil) were stipulated. Table II shows the thermal conditions.

Figures 4–6 show the results of the simulation. For the beampipe to be at 100°C, ~1.3*106 W/m3 is needed. The maximum velocity at the outlet of the annulus, the silicon temperature, and heater pipe upstream temperature were de-

Solver	Fluid Flow Fluent, pressure-based
Model	k-omega, Shear Stress Transport (SST)
Heat transfer	natural and forced convection
Precision	double
Simulation iterations	2500
Heat of source	1,365,516 W/m3
Air temperature	22°C
Airflow velocity (per connector)	27.63 m/s or total 210 L/min

TABLE II. Conditions of thermal simulation.

termined to be 3.4 m/s, 30°C, and 112°C, respectively. The mass flow rate of air at the inlets and outlet of the annulus were the same, 4 g.

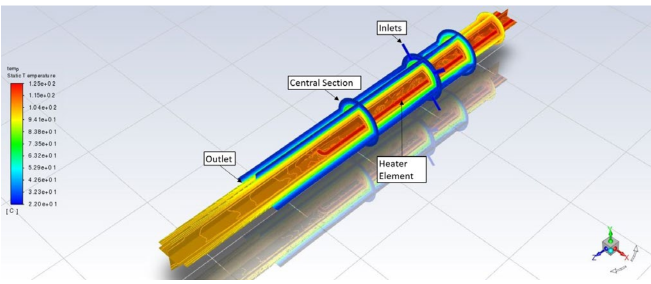

FIG 4. Isometric view of the temperature contour plot with multiple planes placed at critical sections of the model.

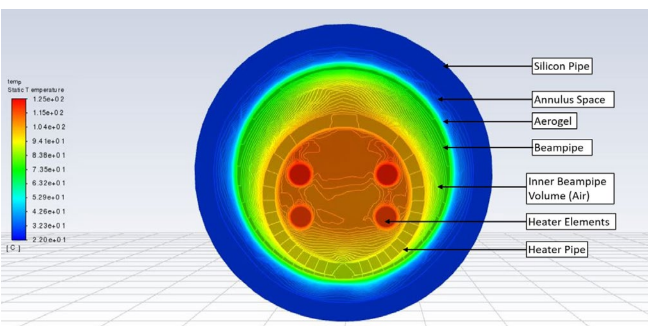

FIG. 5. Front/upstream view of the temperature contour plot for the central section of the model.

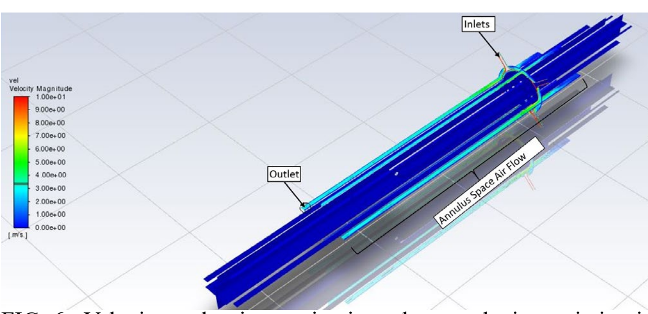

FIG. 6. Velocity v plot, isometric view, shows velocity variation in annulus for inlet airflow of 3.5 L/s. Airflow velocity shown, to make |v| noticeable, is in the range 0–10 m/s (entire range is 0–30 m/s). Dark blue, light blue, and green areas have velocities of ~0, 3.5 and 5.5 m/s respectively.

In conclusion, the Ansys Fluent simulation results and the measured RTD values (test stand) [5] are close, except for the heater pipe temperatures, which are considerably lower in the simulation since the heater element's heat source settings were decreased for the beampipe to be at 100°C.

[1] B.Eng, G. Jacobs, and M. McMullen, et al. *DSG Beampipe Test Stand Functionality Test,* DSG Talk 2023-01, January 2023.

[2] P. Campero, et al., *Ansys Fluent Thermal Analysis of the Beamline Test Stand Assembled with Aerogel*, DSG Note 2023-24, 2023.

[3] G. Jacobs, et al. *Mechanical Design of the EIC Beampipe Thermal Test Stand,* DSG Note 2023-29, 2023.

[4] Z. Nadolny and G. Dombek, *Thermal Properties of Mixtures of Mineral Oil and Natural Ester in Terms of Their Application in the Transformer,* EEMS, 2017.

[5] M. McMullen, et al. *Control and Monitoring of Beampipe Test Stand for the Electron Ion Collider*, DSG Note 2023-26, 2023.