Thermal Analysis of the Beamline Test Stand for the Electron Ion Collider

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This note presents the simulation results of the computational fluid dynamics thermal analysis performed with Ansys Fluent of the heat transfer between the beampipe and the first layer of the silicon tracking sensor (SL1) in the test stand modeled after the Electron Ion Collider's (EIC) beam interaction region. The simulation results show the maximum temperature of SL1 as a function of the air flowing through the annulus—space formed between the beampipe and SL1—and the results are compared to the measurements taken on the test stand.

To validate results obtained on the thermal simulation performed with Ansys Fluent on the interaction of the central section of the EIC beampipe with SL1 [1][2], a test stand was assembled [3]. Since there were significant differences between the test stand and the EIC beampipe model in Fluent, it was decided to simulate the test stand in Fluent and compare the results with the results to the test stand.

The Fluent model of the test stand is shown in Fig. 1. Because of the geometry of the model, the creation of a volume between the outer face of the heater pipe and inner face of the of the beampipe (empty space, with no airflow) was made to ensure heat transfer from the heater to the beampipe is over the entire inner surface, rather than just at the tangential line of contact between the heater and the beampipe.

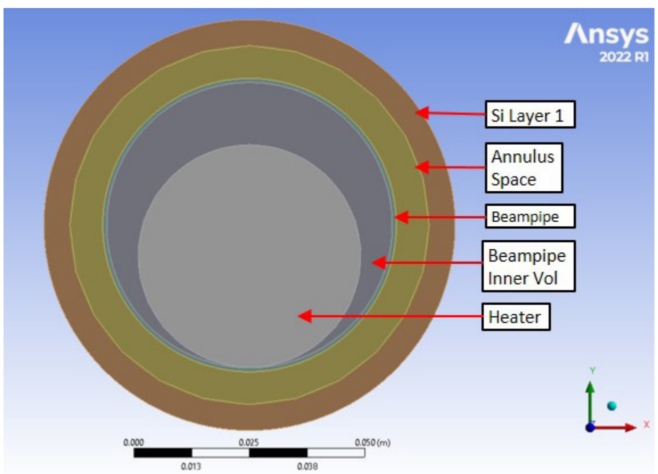

FIG. 1. Front view of model.

The Fluent model dimensions for the simulation, Table I, were based on the components used in the test stand.

Part name	ID [in]	OD [in]	Thickness [in]	Length [in]
Heater pipe	N/A	1.9	N/A	12
Beampipe	2.43	2.5	0.07	12
Si sensor layer 1	3.5	3.06	0.44	12

TABLE I. Model component dimensions.

There is a difference between the test stand and the simulated model in the way air flows through the annulus; for the test stand, compressed air is input by four NTP push-lock connectors; for the Fluent model, the air flow is uniform over the annulus in the axial direction from the inlet end, Fig. 2.

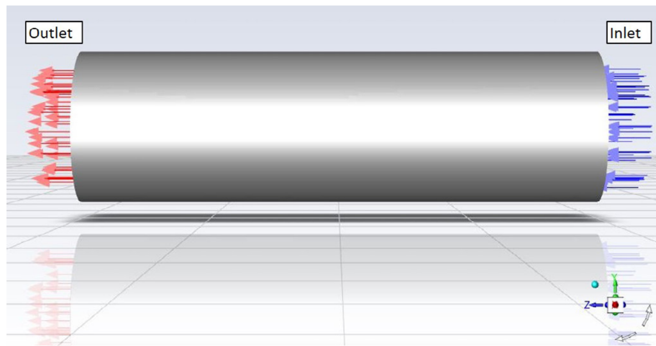

FIG. 2. Air flow setup in Fluent model.

Another difference is that the test stand's outlet is in contact with the atmosphere while in the Fluent model it is not.

Once the geometry was completed using Ansys SpaceClaim software, meshing of the model was done by sharing topology. Mesh methods such as sweep, inflation, and face sizing were used to get an optimal mesh of the model, Fig. 3.

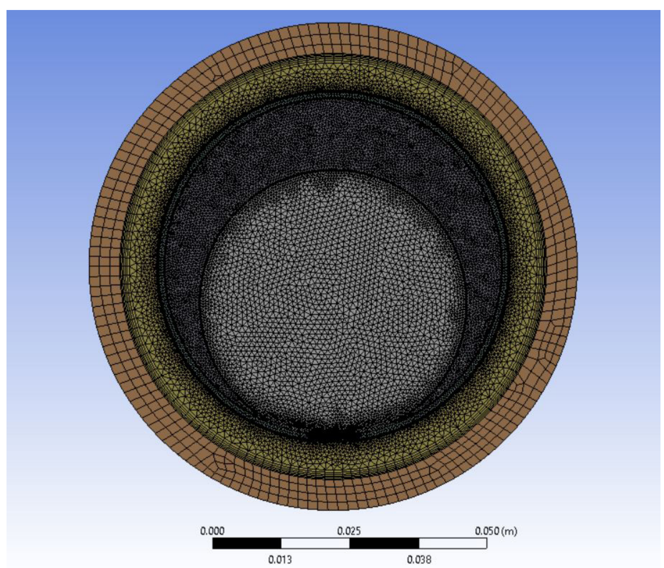

FIG. 3. Mesh for each component of the model.

After setting material properties of the components, Table II, the cell zone conditions were set with the heater pipe as the heat source for the system with a calculated heat rate of 46.4 W for a volume of 5.576×10^{-4} m^3. Boundary conditions were set with the inlet, outlet, internal sections, and walls for each component of the model. Table III shows an overview of the conditions and configurations set for the solver.

Material	Density [Kg/m3]	Specific heat [J/Kg*K]	Thermal conductivity [W/m*K]
Aluminum	2719	871	202.4
Air	1.225	1006.43	0.0242

TABLE II. Material properties.

Solver	Fluid Flow Fluent, pressure-based
Model	k-omega, Shear Stress Transport
Heat transfer	convection and radiation
Precision	double
Simulation iterations	1000
Heat source for system	83229.9 [W/m^3]
Air temperature	20°C
Air flow velocity	0 to 2.1 m/s

TABLE III. Fluent set conditions and solver configurations.

In the generated temperature contour plot, Fig. 4, Fluent temperature probes were placed roughly where the RTD temperature sensors were located in the test stand.

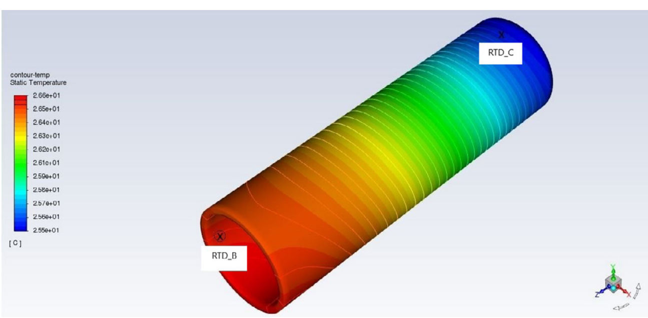

FIG. 4. Contour temperature plot result for SL1 when there is an air inlet flow velocity of 2.1 m/s.

After seven simulations at different air flow velocities through the annulus, the temperatures on SL1 from the simulation and from the measurements were plotted, Fig. 5.

The results of Ansys Fluent analysis show a decrease in SL1 temperature, as airflow increases above 0.5 m/s. The simulated temperature is close to the measured temperature for flows greater than 0.5 m/s.

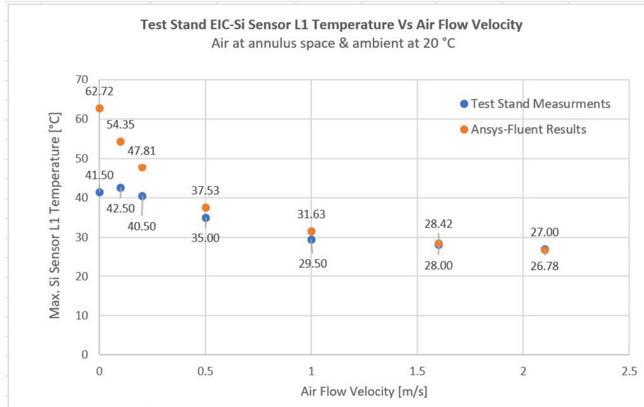

FIG. 5. Comparison between Fluent temperature results and the measured temperature from the test stand.

[1] P. Campero, et al. *EIC –Thermal Analysis of Beryllium section of Beampipe*, DSG Talk 2022-13, 2022.
[2] P. Campero, et al. *Thermal Analysis of the Beryllium Beampipe at Interaction Point 6 of the Electron Ion Collider*, DSG Note 2022-09, 2022.
[3] B.Eng, G. Jacobs, and M. McMullen, et al. *DSG Beampipe Test Stand Functionality Test*, DSG Talk 2023-01, 2023.