Thermal Analysis of Drift Tubes for LEHIPA

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Abstract. A linear accelerator comprising of Radio frequency quadruple (RFQ) and drift tube linac (DTL) is being developed by BARC under LEHIPA (Low Energy High Intensity Proton Accelerator) as front end injector of the 1 GeV accelerator for the ADS programme. This DTL accelerates protons from energy of 3 MeV to 20 MeV. The drift tubes are mounted concentrically inside the resonating DTL tank and are attached to the tank body with stems. About 2.5-4.5 KW of heat generated in each drift tube due to joule losses because of RF heating. Hence drift tubes should be continuously cooled to limit the temperature and resulting thermal deflection. Thermal deflection is required to evaluate frequency shift in the cavity. Analysis was done using CFD code CFD-ACE$^+$ as conjugate heat transfer. Temperature distribution, pressure drop, and thermal deflection have been obtained for a given flow velocity. Effect of flow velocity has been studied on drift tube temperatures.

Keywords: DTL, CFD, drift tube, thermal deflection, frequency shift

INTRODUCTION

A linear accelerator comprising of RFQ and DTL is being developed by BARC under LEHIPA [1] as front end injector of the 1GeV accelerator for the ADS programme. This DTL accelerates protons from an energy of 3 MeV to 20 MeV. In DTL particles are accelerated by longitudinal electric fields at the gap crossings between drift tubes. The permanent magnet quadrupoles are placed inside the hermetically sealed drift tubes and provide a constant magnetic field gradient in the beam aperture. The drift tubes are mounted concentrically inside the resonating DTL tank and are attached to the tank body with stems (see Fig. 1).

FIGURE 1. Drift tubes mounted in the DTL tank

FIGURE 2. Drift tube assembly with embedded permanent magnet quadrupoles

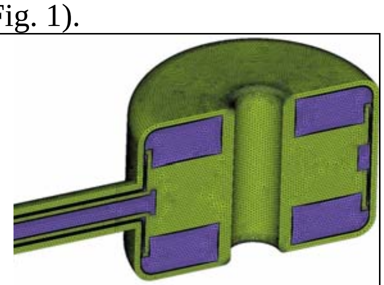

FIGURE 3. Meshed geometry of the Drift Tube

About 2.5-4.5 kW of heat is generated in each drift tube due to joule losses because of RF heating. Hence drift tubes should be continuously cooled to limit the temperature and resulting thermal deflection. Thermal deflection is required to evaluate frequency shift in the cavity. Drift tubes are mounted inside a vacuum cavity. The thermal hydraulic analysis of the drift tube has been carried out. Heat loss from DTL was assumed to be by convection loss to cooling water circulating in the inner channels. The temperature rise of the drift tube assemblies has been limited to avoid demagnetization of permanent magnets and also to limit thermal expansion of the tubes. A prototype model was made by CnID [2], BARC and sketch of the same is shown in Fig. 2. There are 4 DTL tank of 3.2 m length each and number of drift tubes in a tank will varies from 37 in first tank to 21 in last tank. Since total heat loss will be different in each drift tube and it will be maximum for last drift tube of last tank. Two drift tubes (last drift tube of last tank, DT-0420; and first drift tube of third tank, DT0302) have been anaylised.

ANALYSIS

Analysis was done using CFD code CFD-ACE$^+$ [3] as conjugate heat transfer with turbulence model. Heat generation on outer surface due to RF heating is specified as heat flux boundary condition on outer surface. Temperature distribution, pressure drop, and thermal deflection have been obtained for a given flow velocity. Effect of flow velocity and change in the outer channel flow gap have been studied on drift tube temperatures. Frequency shift for one of the DTL tank has been evaluated based on Salter Perturbation theory. Drift tube is a complex structure in which first water enters into inner channel and goes to outer channel and comes out of outer channel on the same stem. Based on feedback from thermal analysis, outer channel size was modified. Due to thermal symmetry only one half of the geometry including stem was modeled. Heat load and geometry details were provided as input by CnID [2] by using code Superfish [4]. Heat generation due to joule heating is applied as heat flux on the outer surface of the drift tube. Uniform flow velocity of water at inlet and pressure boundary condition was specified at outlet of the cooling channel. At mid plane, symmetric boundary condition was applied and low Re turbulence model is used. A coupled analysis has been carried out in which temperature distribution is obtained as conjugate heat transfer and resultant deflection is obtained based on temperature distribution. Stem end attached to the DTL tank assumed as fixed deflection boundary condition. Mesh of the geometry used for the analysis is shown in Figure 3. Due to complex geometry, mesh was generated using tetra cells. But boundary layer mesh is generated on the fluid-solid interface. About 1.8 million cells were used in the analysis. Mesh is generated such that to maintain y^+ [5] for low Re turbulence model. To limit the erosion and flow induced vibration fluid velocity in the copper should be less than 2.5 m/sec [6].

Frequency Shift

Thermal deflection caused by RF heating results in frequency shift as the shape and volume of the cavity changes. For any given cell, the frequency shift can be calculated using Slater perturbation theory and given as

$$\frac{df}{f} = \frac{\int(\mu H^2 - \varepsilon E^2)dV}{4U}$$

Where df is a function of the volume change of an infinitesimal volume dV at the RF surface, H and E are the electromagnetic and electric filed respectively. And μ and ε are the free space permeability and permittivity, respectively and U is the cavity stored energy.

RESULT & DISCUSSION

Steady state temperature distribution has been evaluated for different DTs and effect of water flow velocity on DT temperature is evaluated. Temperature distribution has been obtained for number of cases and maximum temperature is shown in Table-1 for DT-0420 and DT-0302 for same velocity input (2 m/sec). Velocity Contours plot for the case of flow velocity of 2 m/sec are shown in Fig. 4 and 5, which shows that flow velocity is maximum in the inner channel as comparison to outer. Flow velocity in the outer channel changes continuously and minimum is at the mid region of the outer channel.

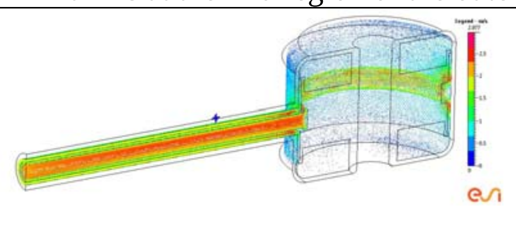

FIGURE 4. Vector Plot (flow velocity =2 m/s)

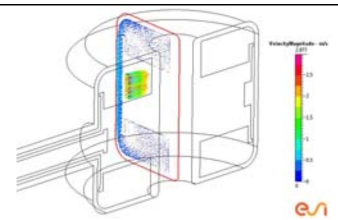

FIGURE 5. Vector Plot (flow velocity =2 m/sec)

Temperature contour plot for drift tube DT0302 is shown in Fig. 6 & 7. Maximum temperature is on the outer surface of drift tube which is 325.7 K. For all the cases, water inlet temperature of 293 K (20 °C) was assumed.

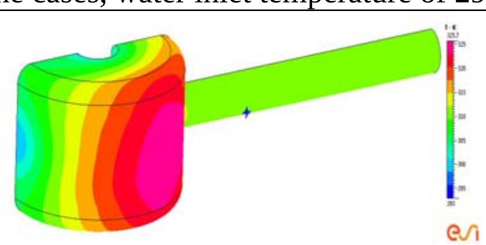

FIGURE 6. Temperature Contour Plot

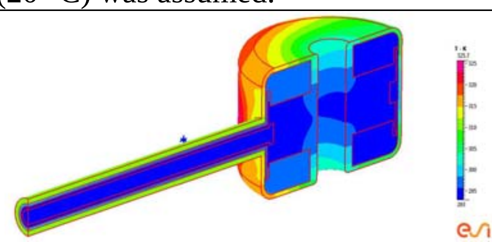

FIGURE 7. Temperature Contour Plot

Figure 8 shows pressure contour plot for DT0-302. Resultant thermal deflection for the case of DT-0302 and flow velocity of 2 m/s is shown in Fig. 9, which shows that thermal deflection is maximum at the tip of the drift tube in axial direction of stem. Combined frequency shift obtained for drift tube DT-0302 and third DTL tank (average tank temperature of 28.4 C, material-carbon steel) is -34.4 kHz. Over all pressure drop in the channel from inlet to outlet is shown in TABLE 1 and for flow velocity of 2 m/s is shown in Fig. 8.

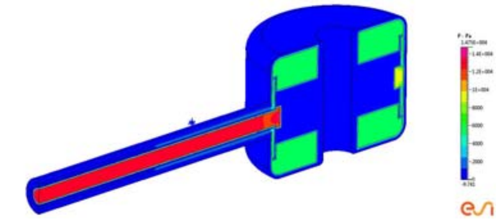

FIGURE 8. Pressure Contour Plot

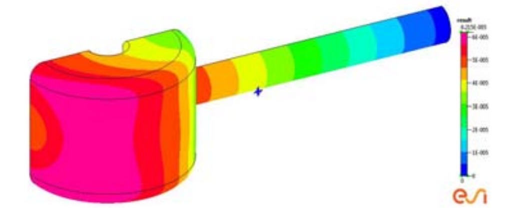

FIGURE 9. Resultant thermal deflection plot

Effect of flow velocity on drift tube temperature is studied. Figure 10, 11 and 12 shows effect of flow velocity on drift tube (for DT0302) temperature, thermal deflection and pressure drop respectively. FIGURE 10 shows maximum and average temperature in the drift tube.

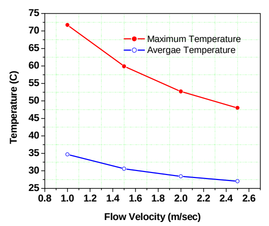

FIGURE 10. Variation of drift tube temperature with velocity

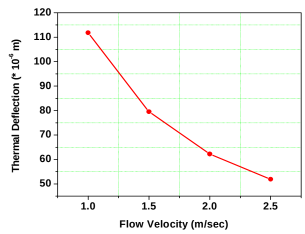

FIGURE11. Variation of thermal deflection with velocity

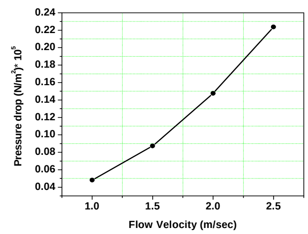

FIGURE 12. Variation of pressure drop with velocity

TABLE 1.

Drift Tube	Heat Load (kW)	Max. Temp. (C)	Thermal deflection (micron)	Pressure drop (N/m^2)
DT-0302	3.9	52.7	62.2	0.1475 E+05
DT-0420	4.8	55.5	72.9	0.1541 E+05

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