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Thermal-Hydraulic Analyses of Drift Tube in Proton Beam Accelerator

Kyung-Jin Lee [a*], Jae-Seon Cho [a], Han-Sung Kim [b], Hyeok-Jung Kwon [b]
[a] *FNC Technology Co., Bldg.#135, Seoul Nat'l Univ., Shilim9-dong, Gwanak-gu, Seoul, 151-742, Korea*
[b] *Korea Atomic Energy Research Institute, 150-1 Deokjin-Dong, Yusung-gu, Daejeon, 305-333, Korea*
[*] *Corresponding author : cagelee@fnctech.com*

1. Introduction

A 100 MeV, 20 mA proton linear accelerator is being constructed as a part of the Ministry of Science and Technology's (MOST) 21st Century Frontier Projects, the Proton Engineering Frontier Project (PEFP) [1]. In 1st phase of accelerator construction, a conventional 20MeV drift tube linac (DTL) has been developed as a low energy section of a 100 MeV accelerator. Computational analyses are performed to investigate the thermal hydraulic characteristics of the drift tube system

2. Drift Tube of Proton Beam Accelerator

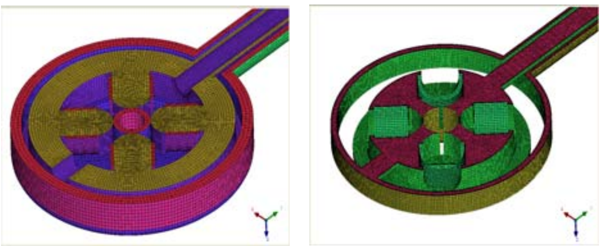
The DTL accelerates the proton beam of 20mA from 3 MeV to 20 MeV for the 1st phase of the project, and the DTL of the PEFP 20 MeV accelerator consists of four tanks and are driven with a single klystron. The installation and alignment of drift tube into the four tanks of the PEFP 20 MeV DTL have been completed [2]. Drift tubes of the PEFP 20MeV DTL contain an electro-quadrupole magnet (EQM) which is composed of a commercial enamel wire cooled with water and total 148 drift tubes are installed in DTL. Drift tube was designed by keeping constant length and slightly increased the thickness of coolant region of EQM body from 1st drift tube to 148th drift tube. Each drift tube has four quadrupole electromagnet cooled by water, and each quadrupole are wound by enamel coil for current induction. During the traverse of the coolant water through the drift tube device, internal heat is generated in quadrupole electromagnet part and the coolant flows through the quadrupole electromagnet. By means of internal heat, the coolant temperature is raised and the drift tube requires enough cooling capability to maintain its integrity. Fig. 1 shows the drift tube assembled body and inside structure [3].

Fig. 1. Drift Tube Structure

3. Calculation Domain and Modeling

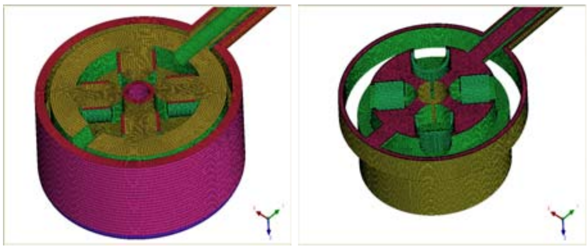
3.1 Calculation Domain

Computational analyses were performed to investigate the thermal hydraulic characteristics of the water coolant and the heat conduction of drift tube solid structure by using computational fluid dynamics code CFX11 [4]. In this study, the coolant region and solid structure region were conjugated to calculate heat transfer at the interface regions. Therefore, the calculations were conducted including coolant region and solid structure region simultaneously. Three-dimensional (3-D) models of the drift tube geometry were established and meshes were generated for both coolant and solid domains of the 1st and 148th drift tubes respectively representing as the Fig. 2 and 3. The geometry (CAD model) was designed by commercial CAD tools and it was imported by CFX mesh tool. Generally, commercial 3D mesh generation tools support both meshes of hexa and tetra type.



(a) Mesh of solid region (b) Mesh of coolant region

Fig. 2. Meshes of 1st Drift Tube



(a) Mesh of solid region (b) Mesh of coolant region

Fig. 3. Meshes of 148th Drift Tube

3.2 Boundary and Initial Conditions

The calculations were performed for 1st drift tube and 148th drift tube with variable coolant injection rates of 5, 10 and 15 lpm (liter per minute). The turbulence model (RNG κ-ε) was applied, and the flow was assumed that fluid properties are varying with temperature change. Initial temperature of 38°C was applied to the solid region and coolant region. In the solid structure mesh, the pole faces were wounded by copper coils. And this copper coil was assumed as one volume and roughness condition was applied to simulate the gaps between each coil turn. The heat sources to induce temperature raise of 1st and 148th drift tubes are presented in Table 1.

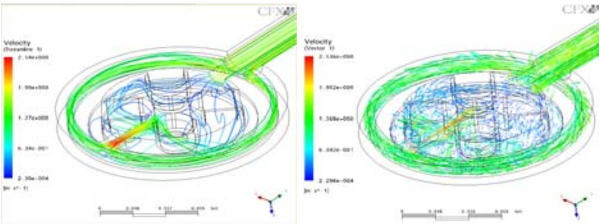
Table 1. Heat sources of drift tube

	1st DT	148th DT
Drift tube main body outer surface	160 W	300 W
Drift tube stem outer surface	104 W	112 W
Heat generation rate of each pole	350 W	350 W

4. Calculation Results

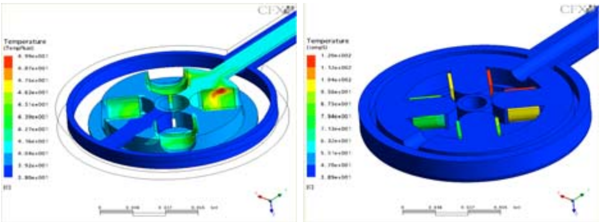
In this study, we evaluated several different flow rates of 5 lpm, 10 lpm and 15 lpm to assess the flow rate effect on the thermal hydraulic characteristics and temperature distribution in the drift tube.

Fig. 4 and 5 represent the coolant behavior and temperature distribution in 1st drift tube under the 10 lpm coolant injection rate and 38°C inlet temperature conditions. As shown in Fig. 4, the coolant flows appropriately from inlet to outlet without obvious stagnation, but the flow velocity was very low around EQM region. The maximum velocity was 2.54 m/sec in the drift tube inside. The temperature of coolant was almost uniform before going into the drift tube main body inside, and varied near the EQM region by heat generated by EQM coil as shown in Fig. 5 (a). The maximum coolant temperature was 50°C near the EQM, which is located in coolant outlet direction. The maximum drift tube solid temperature showed 120°C at the EQM located in coolant outlet direction, but as described in above, the maximum coolant temperature was obviously low than boiling temperature. This means that the coolant boiling does not occur in the drift tube.



(a) Coolant stream line (b) Vector profile

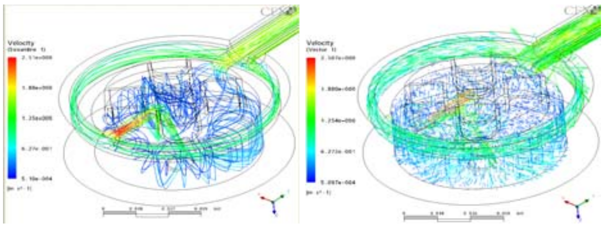
Fig. 4. Coolant Behavior of 1st Drift Tube



(a) Coolant region (b) Solid region

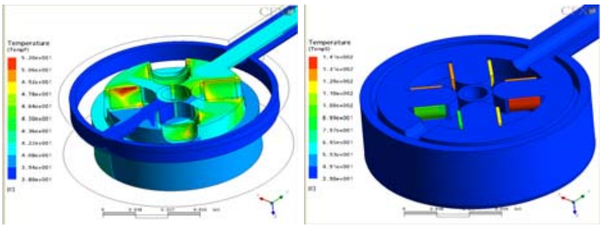
Fig. 5. Temperature Distribution of 1st Drift Tube

Fig. 6 and 7 represent the coolant behavior and temperature distribution in 148th drift tube under the 10 lpm coolant injection rate and 38°C inlet temperature conditions. As shown in Fig. 6, the coolant flows appropriately from inlet to outlet without obvious stagnation. The maximum velocity was 2.51 m/sec in the drift tube inside. The maximum coolant temperature was 52°C near the EQM, which is located in coolant outlet direction. The maximum drift tube solid temperature showed 141°C at the EQM located in coolant outlet direction. Table 2 represents the calculation results of maximum temperatures for each case.



(a) Coolant stream line (b) Vector profile

Fig. 6. Coolant Behavior of 148th Drift Tube



(a) Coolant region (b) Solid region

Fig. 7. Temperature Distribution of 148th Drift Tube

Table 2. Maximum temperature Results of 1st and 148th Drift Tubes

Flow Rate	5 lpm		10 lpm		15 lpm	
	1st DT	148th DT	1st DT	148th DT	1st DT	148th DT
Coolant Outlet Temperature(°C)	43.6	44.4	40.8	41.1	39.6	40.1
Coolant Max. Temperature(°C)	59.8	59.7	49.9	52.0	46.5	50.1
Solid Max. Temperature(°C)	175.4	205.2	119.6	140.6	98.3	118.3

5. Conclusions

Generally, temperature rise by heat transfer requires enough time of heat transfer at the interface of two different materials. In this case, the coolant passes rapidly on the EQM heating surface and exits to the outlet before achievement boiling temperature. Therefore, it is confirmed that the coolant boiling would not be occurred in the drift tube inside structure.

REFERENCES

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