Experimental and Multi-physics Analysis on Drift Tube for Separated Drift Tube Linac

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1. Introduction

To accommodate a potential 200 MeV energy upgrade at the Korea Multi-purpose Accelerator Complex (KOMAC), a separated drift tube linac (SDTL) configuration is under evaluation. This paper focuses on the development and evaluation of the initial drift tube positioned within the first tank. To efficiently manage RF thermal loads, the drift tube features a customized design utilizing isolated cooling pathways in its central and peripheral sections. The viability of this design is assessed using both experimental and computational methods. Specifically, a transparent acrylic prototype is constructed for empirical flow visualization and pressure drop measurements. In parallel, a comprehensive multi-physics analysis incorporating electromagnetic, thermal, and structural analyses is executed to evaluate structural stability and frequency detuning under operating conditions.

2. Methods and Results

2.1 Drift Tube Design

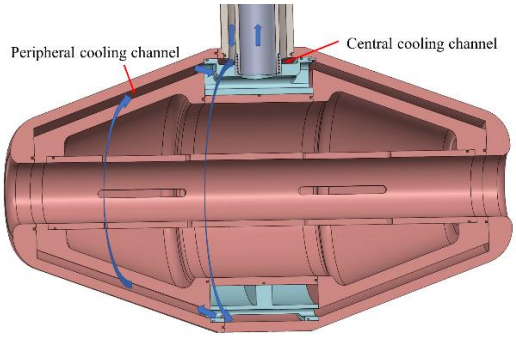


Fig. 1. Cross-sectional view of the drift tube. (arrows in blue describe flow of coolant inside the drift tube)

Figure 1 illustrates the cross-sectional view of the drift tube. The external geometry of the drift tube is optimized to maximize acceleration efficiency while mitigating the risk of electrical breakdown. [1] Given its elongated geometry and thick central section, independent cooling channels are allocated for the central and peripheral zones. The coolant enters through the outer channel of the stem, passes through the central channel, and feeds into the lower peripheral channels. It then circulates upward through these peripheral paths, reconverges at the top, and is ultimately discharged via the internal channel of the stem. In the absence of an internal quadrupole magnet, the drift tube accommodates only these cooling passages. Additionally, the remaining internal sections are designed to be hollow to achieve significant weight reduction.

2.2 Coolant Flow Test on Drift Tube



Fig. 2. Acrylic drift tube prototype with a manifold for coolant flow test.

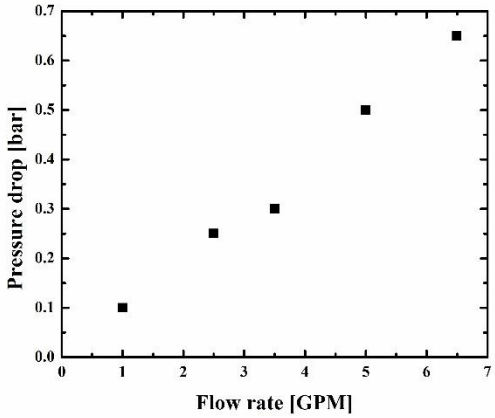


Fig. 3. Pressure drop across the drift tube according to flow rate.

To empirically verify the internal coolant flow of the drift tube, an acrylic-based transparent prototype is fabricated, as shown in Fig. 2. To evaluate hydraulic performance, the pressure drop across the cooling channels is measured as a function of the flow rate. As illustrated in Fig. 3, the pressure drop exhibits a linear relationship with the flow rate. When the coolant temperature rise is limited to 1°C under a 3% RF duty cycle, the required flow rate is 6.5 GPM, which incurs a pressure drop of 0.6 bar. This operating point confirms that the required hydraulic conditions can be sufficiently accommodated by the nominal cooling system. Furthermore, a flow visualization test is performed by introducing blue tracer particles into the working fluid (Fig. 4) to enable direct observation and qualitative assessment of the internal fluid flow. A relatively uniform flow distribution is observed within the central cooling channel. Conversely, in the peripheral channels, the flow is primarily concentrated in the upper and lower regions because the interconnecting passages linking the central and peripheral channels are positioned at the top and bottom. Consequently, a stagnation zone characterized by recirculating flow developed along the lateral regions of the peripheral channels, where the blue tracer particles were observed to swirl. However, because these tracer particles eventually exit the region rather than remaining trapped, it can be inferred that the coolant circulates effectively without permanent stagnation, despite the localized temporary circulation.

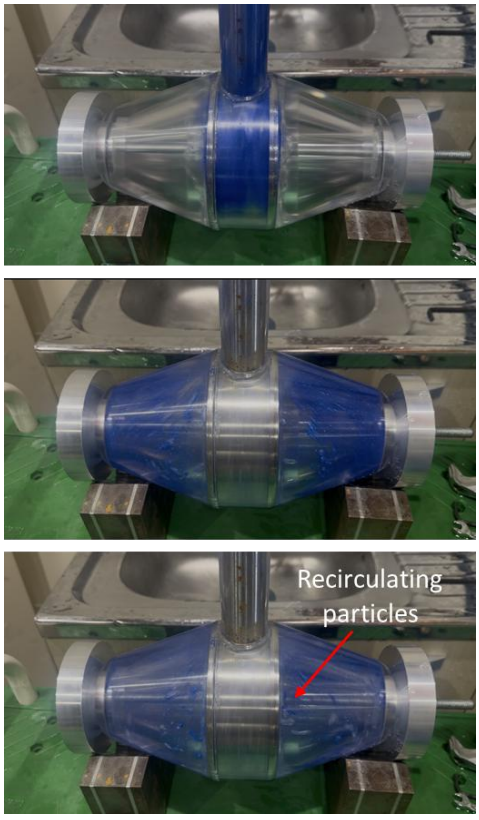


Fig. 4. Flow visualization test with blue tracer particles.

2.3 Multi-physics Analysis on Drift Tube in Tank

A multi-physics analysis is conducted on the drift tube to determine the frequency detuning under operational conditions. Although the 3D model includes the cavity tank wall and other drift tubes, the thermal and structural simulations are restricted solely to the target drift tube to focus specifically on its contribution to frequency detuning. The sequential analysis workflow is as follows: first, an electromagnetic simulation is performed to derive the RF heat dissipation at an RF duty factor of 3%. Next, the resulting temperature profile and corresponding structural displacements are calculated through thermal and structural analyses, respectively, using a reference temperature of 27°C. Finally, the frequency detuning induced by this structural deformation is evaluated via a subsequent electromagnetic analysis. For the cooling system, a coolant flow velocity of 2.5 m/s is prescribed, and the heat transfer coefficients of the cooling channels are determined using the Dittus-Boelter equation. [2] Notably, the heat transfer coefficient for the peripheral cooling channel is assumed to be one-tenth of that of the central channel; this adjustment is due to the complex internal flow behavior within the peripheral paths, which precludes them from being characterized by a single uniform flow. The calculated heat transfer coefficients for each cooling channel are summarized in Table 1.

Table 1: Heat transfer coefficients for each cooling channel

Cooling channel	**Heat transfer coefficient** $[W/m^2K]$
Central	6000
Peripheral	600
Stem	8000

The thermal and structural analysis results are presented in Fig. 5. The drift tube exhibits a maximum temperature rise of up to 44.2°C, which induces a peak displacement of 25.7 μm. Consequently, the component remains well within the prescribed alignment tolerance of 50 μm under operational conditions. Furthermore, the calculated von Mises stress within the drift tube does not exceed the yield strength of its constituent materials, thereby validating that structural integrity is preserved during operation. Based on the displacement distribution, the frequency detuning contributed by the drift tube is evaluated. When utilizing the heat transfer coefficients listed in Table 1, the frequency detuning is determined to be -8.2 kHz. Figure 6 delineates the frequency detuning as a function of the coolant temperature, yielding a frequency sensitivity of -0.7 kHz/°C. This suggests that reducing the coolant temperature by 5°C relative to the reference temperature can successfully mitigate the frequency detuning to within 5 kHz. Additionally, the sensitivity of the frequency detuning to the heat transfer

coefficient of the peripheral channel is investigated, with the results shown in Fig. 7. To prevent an abrupt increase in the frequency detuning magnitude, the heat transfer coefficient must be maintained above 600 W/m^2K. Under the assumption of uniform channel flow, the Reynolds number remains below 4000, indicating that the fluid flow lies within the transition regime. Even under a conservative laminar flow assumption [3], the heat transfer coefficient exceeds the threshold value specified in Table 1. Therefore, the peripheral channels are expected to ensure sufficient cooling performance, successfully avoiding the regime of abrupt detuning inflation.

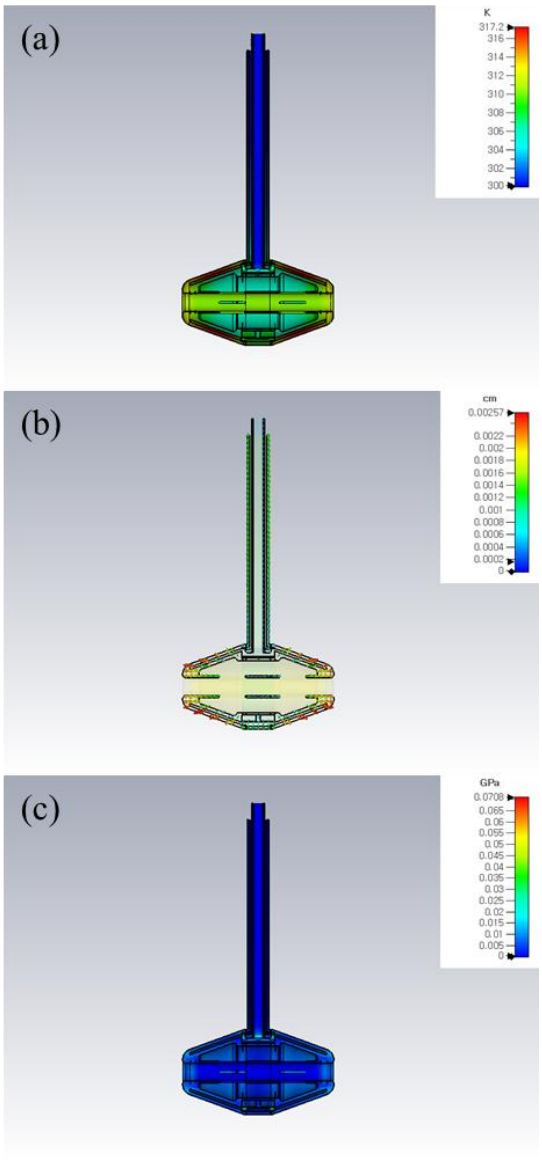


Fig. 5. Thermal and structural analysis results: (a) temperature, (b) displacement, and (c) von mises stress distribution.

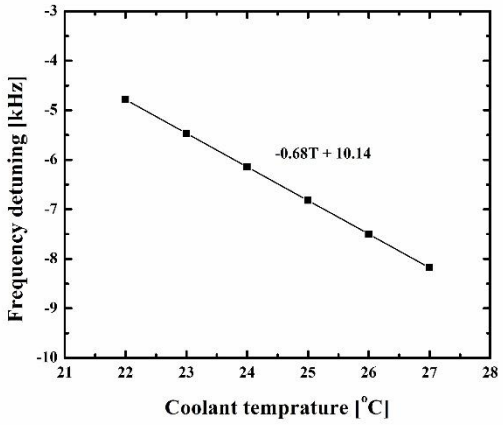


Fig. 6. Frequency detuning by the drift tube according to temperature of the coolant.

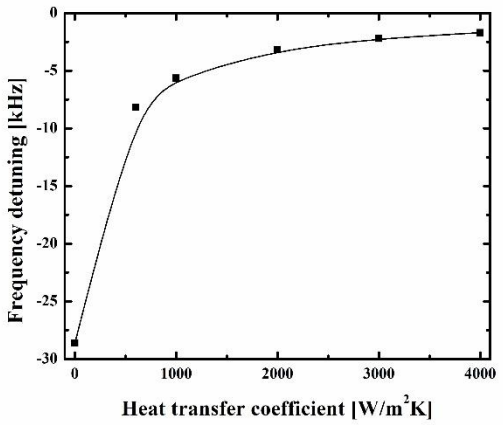


Fig. 7. Frequency detuning by the drift tube according to the heat transfer coefficient of the peripheral cooling channel.

3. Conclusions

This study demonstrates the design feasibility of a novel drift tube for an SDTL utilizing a coupled experimental and numerical approach. Although localized recirculation is observed within the peripheral cooling channels, flow visualization confirms efficient coolant circulation without permanent fluid stagnation. Concurrently, numerical investigations verify that the structural integrity of the drift tube is strictly preserved under operational conditions, and the thermal-hydraulic cooling performance is sufficient to successfully mitigate frequency detuning. Consequently, the proposed design is proven to be highly robust and well-suited for integration into SDTL structures.

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REFERENCES

[1] S. Park *et al.*, "Accelerating cell design optimization for separated drift tube linac in KOMAC", *J. Kor. Phys. Soc.*, vol. 87, no.7, pp.920-930, 2025.

[2] R. H. S. Winterton, "Where did the Dittus and Boelter equation come from?", *Int. J. Heat Mass Transfer.*, vol. 41, pp.809-810, no.4-5, 1998.

[3] V. V. Satyamurty and R. Repaka, "Local Nusselt Numbers for Flow Through Asymmetrically Heated Parallel Plate Channels by Superposition", in *Proc. 20th National and 9th international ISHMT-ASME Heat and Mass Transfer Conference,* Mumbai, India, Jan 2010.