Transactions of the Korean Nuclear Society Autumn Meeting
Changwon, Korea, October 30-31, 2025

Electro-thermal analysis on 200 MeV separated drift tube linac in KOMAC

Sungbin Park [a*], Han-Sung Kim [a], Hyeok-Jung Kwon [a]
[a]*Korea Multi-purpose Accelerator Complex, Korea Atomic Energy Research Institute, Gyeongju 38180, South Korea*
[*]*Corresponding author: sbpark95@kaeri.re.kr*

***Keywords :** separated drift tube linac, electro-thermal analysis, resonance frequency of TM and TE mode, tilt sensitivity, frequency detuning

1. Introduction

Korea Multi-purpose Accelerator Complex (KOMAC) has been preparing 200 MeV energy upgrade to meet increasing demands on radiation effect test in various fields such as semi-conductor and space industry. [1,2] In the acceleration process up to 200 MeV, separated drift tube linac (SDTL) structure can be used. As quadrupole magnet is situated outside of the drift tube in SDTL, it has advantage for optimizing drift tube design. [3] In this study, electro-thermal analysis on the first tank of the SDTL is conducted with CST microwave studio. [4] Varying parameters, resonance frequency of the TM and TE mode, tilt sensitivity, and frequency detuning of the tank are discussed.

2. Methods and Results

In this section, electro-thermal analysis results are represented. It is noted that targeted resonance frequency of the SDTL tank is 350 MHz and reference temperature is 27℃. Tank geometry composed of 6 cells is obtained from the PARMILA code based on the cell design described in the Table I. [5, 6] 3D model of the tank is shown in Fig. 1.

Table I: Design parameters of cell

Tank diameter [mm]	480.335
Drift tube diameter [mm]	140
Face angle [◦]	70
Outer nose radius [mm]	18
Inner nose radius [mm]	4.5
Flat length [mm]	1
Bore radius [mm]	15
Corner radius [mm]	1
Stem diameter [mm]	36

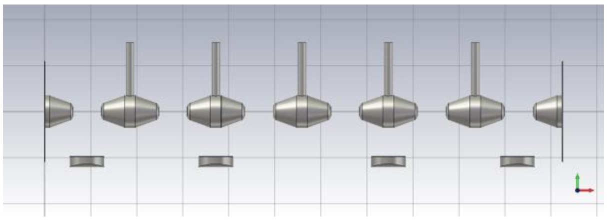

Fig. 1. 3D model of the SDTL tank. Tank wall and endplates are hidden.

2.1 Resonance frequency of TM and TE mode according to insertion depth of tuners

Figure 2 shows resonance frequency of the first TM and TE mode according to the insertion depth of tuners. When resonance frequency of TM mode reaches 350 MHz, that of TE mode is about 2 MHz lower. As a result, operating mode (TM mode) seems stable from the mode transition between adjacent modes. This result stems from the positioning of tuners which are located near either side of the tank avoiding central region. As TE mode has maximum field at the central region, resonance frequency of TE mode would be closer to that of TM mode if tuners located near the central region according to Slater perturbation theorem. [7]

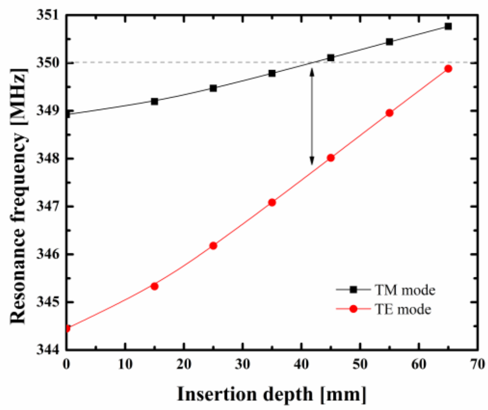

Fig. 2. Resonance frequency of the first TM and TE mode according to the insertion depth of tuners.

2.2 Tilt sensitivity

Figure 3 shows tilt sensitivity analysis result by inserting the first (last) tuner 10 mm and extracting the last (first) tuner on the amount that maintains the same resonance frequency. It is noted that initial insertion depth is fixed with 41.8 mm which derives resonance frequency of 350 MHz. It is seen that tilt sensitivity is 80%/MHz which is suitably small due to its short tank length. (~2250 mm) Therefore, additional post coupler for field stabilization is not required which gives simplicity in tank fabrication.

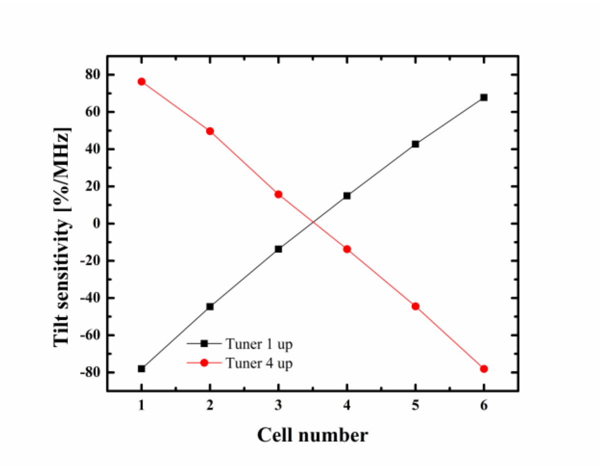

Fig. 3. Tilt sensitivity analysis result on the SDTL tank.

2.3 Frequency detuning of the tank

Frequency detuning analysis is conducted from the following flow. First, electromagnetic analysis is conducted to derive electromagnetic field structure in the tank. Then, thermal analysis is conducted from RF heat source obtained in the electromagnetic analysis assuming duty factor of 3%. Then, structural analysis is conducted from temperature distribution obtained in the thermal analysis. Finally, electromagnetic analysis is again conducted to obtain frequency detuning from displacement distribution obtained in the structural analysis. In the following paragraphs, frequency detuning from tank wall, drift tube, and stem are investigated independently. Figure 4 shows cooling channels adapted in this analysis. It is noted that reference flow velocity of cooling water is 2.5 m/s. With that flow velocity, coolant temperature increase is expected less than 1℃. In thermal analysis it is assumed that temperature of cooling water does not change. Additionally, in structural analysis of tank wall and stem, boundary condition that assumes no length expansion is applied.

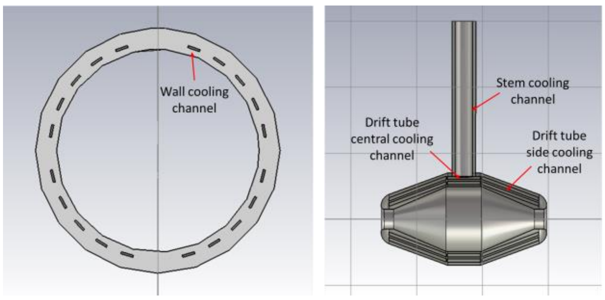

Fig. 4. Cooling channels of tank wall, drift tube, and stem adapted in this analysis.

Tank wall material is assumed as stainless steel. In tank wall, 20 cooling channels with width of 30 mm and height of 5 mm is considered. According to Dittus-Boelter equation, heat transfer coefficient of each channel is estimated as 10000 W/m^2K with flow velocity of 2.5 m/s. [8] Figure 5 shows frequency detuning from tank wall according to heat transfer coefficient of the cooling channel. As the heat transfer coefficient becomes larger, detuning value gradually converges. When heat transfer coefficient is sufficiently large, temperature difference at the interface of cooling channel and wall becomes small. Then, temperature distribution is almost determined by thermal properties of materials and frequency detuning would converges to a certain value. However, when heat transfer coefficient is small, the temperature distribution is floated on the amount of the temperature difference at the interface which increases frequency detuning. In this analysis, it seems that the boundary between those two situations is around 6000 W/m^2K.

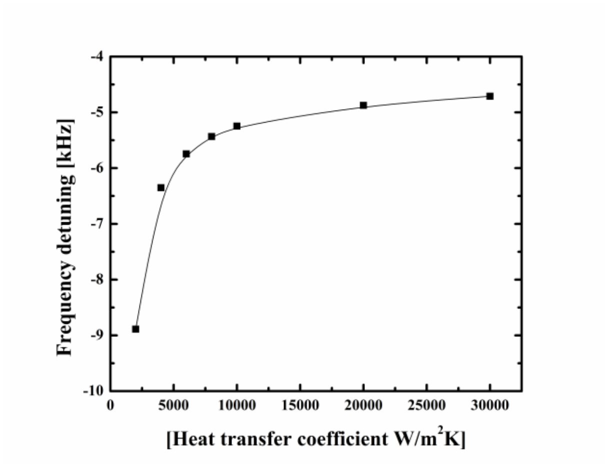

Fig. 5. Frequency detuning from tank wall according to heat transfer coefficient of the cooling channel.

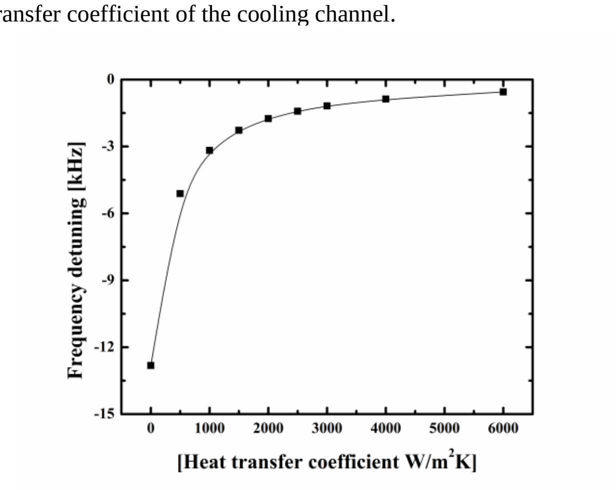

Fig. 6. Frequency detuning from drift tube according to heat transfer coefficient of the side cooling channel when that of central cooling channel is fixed as 6000 W/m^2K.

Drift tube material is assumed as copper. In drift tube, cooling channels consist of central and side channel. Heat transfer coefficient of central and side channel are estimated as 6000 W/m^2K and 2000 W/m^2K respectively. However, side channel does not satisfy turbulent flow condition which is not suitable for applying Dittus-Boelter equation. Figure 6 shows frequency detuning from drift tube according to heat transfer coefficient of side channel when that of central channel is fixed with 6000 W/m^{2}K. It is noted that Fig. 6 represents 6 times of that from the last drift tube where electromagnetic field is the strongest. In drift tube case, the boundary appears around 1000 W/m^{2}K.

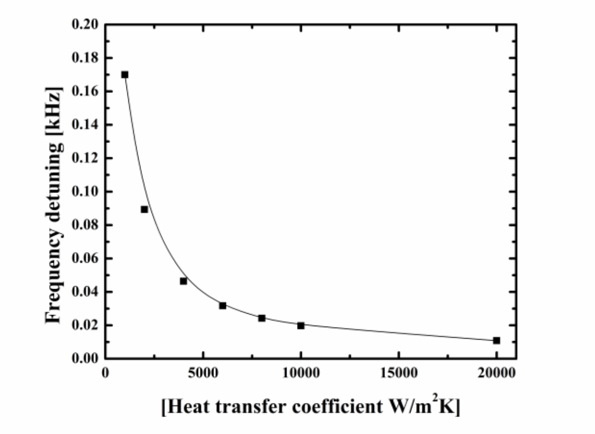

Fig. 7. Frequency detuning from stem according to heat transfer coefficient of the cooling channel.

Stem material is assumed as copper. When thickness of outer shell of stem is 4.5 mm and inner cooling channel's diameter is 10 mm, heat transfer coefficient is estimated as 8000 W/m^{2}K when inner cooling channel is ignored. Figure 7 shows frequency detuning from stem according to heat transfer coefficient of cooling channel. Likewise, it represents 6 times of that from the last stem. In the considered range of heat transfer coefficient, frequency detuning is less than 1 kHz which is negligible compared to other components.

3. Conclusions

Electro-thermal characteristics on the first tank of the SDTL are investigated. At the targeted resonance frequency of 350 MHz, it is found that deviation between TM and TE mode is more than 2 MHz which is adequate for stable operation without mode transition. In addition, as tilt sensitivity is sufficiently small (80%/MHz), post coupler stabilization can be omitted for the simplicity of tank fabrication. Under RF duty factor of 3%, frequency detuning of the tank is investigated. According to heat transfer coefficient, characteristic behavior of the frequency detuning is found which implies suitable value of heat transfer coefficient to minimize the frequency detuning.

ACKNOWLEDGEMENT

This work has been supported through KOMAC (Korea Multi-purpose Accelerator Complex) operation fund of Korea Atomic Energy Research Institute by the Ministry of Science and ICT (MSIT) (No. 524320-25)

REFERENCES

[1] S. Lee, S. Yoon, H. Kim, and H. Kwon, Improvement of beam uniformity for radiation effect test on electronic devices for space applications at KOMAC, Journal of the Korean Physical Society, Vol.83, p.743, 2023.

[2] C. L. Morris, E. N. Brown, C. Agee, T. Bernert, M. A. M. Bourke, M. W. Burkett, W. T. Buttler, D. D. Byler, C. F. Chen, A. J. Clarke, J. C. Cooley, P. J. Gibbs, S. D. Imhoff, R. Jones, K. Kwiatkowski, F. G. Mariam, F. E. Merrill, M. M. Murray, C. T. Olinger, D. M. Oro, P. Nedrow, A. Saunders, G. Terrones, F. Trouw, D. Tupa, W. Vogan, B. Winkler, Z. Wang, and ,M. B. Zellner, New Developments in Proton Radiography at the Los Alamos Neutron Science Center (LANSCE), Experimental Mechanics, Vol.56, p.111, 2015.

[3] G. Shen and M. Ikegami, Tuning of RF amplitude and phase for the separate-type drift tube linac in J-PARC, Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, Vol.598, p.361, 2009.

[4] CST Microwave Studio. Accessed: Aug. 19, 2025. [Online]. Available: http//www.cst.com

[5] H. Takeda and J. H. Billen, PARMILA Manual, Rep. LA-UR-98-4478, 1998, Los Alamos Nat. Lab. (Revised July 26, 2005).

[6] S. Park, S. Lee, H. -S. Kim, and H. -J. Kwon, Accelerating cell design optimization for separated drift tube linac in KOMAC, Journal of the Korean Physical Society, 2025.

[7] T. P. Wangler, RF Linear Accelerators, John Wiley & Sons, New York, 1998.

[8] R. H. S. Winterton, Where did the Dittus and Boelter equation come from?, Int. J. Heat Mass Transfer., Vol. 41, p.809, 1998.