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Multi-physics analysis on 6-cell separated drift tube linac tank

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1. Introduction

Korea Multi-purpose Accelerator Complex (KOMAC) has been designing 200 MeV linac to meet increasing demands on radiation effect test in various fields such as semi-conductor and space industry. [1,2] For the acceleration up to 200 MeV, both normal conducting and superconducting system can be utilized. In this study, normal conducting separated drift tube linac(SDTL) structure is considered which has advantage for optimizing drift tube(DT) design as quadrupole magnet is situated outside of the DT. [3] To investigate the characteristics of the SDTL tank during operation, multi-physics analysis on the 6-cell SDTL tank is conducted with CST microwave studio. [4] Through electro, thermal, and structural analysis, temperature and displacement distribution of the tank is found and structural integrity is examined. Then, frequency detuning of the tank during operation is obtained. In addition, appropriate coolant temperature and insertion range of movable tuner are investigated to compensate that frequency detuning.

2. Methods and Results

In this section, multi-physics analysis results are represented. First, electromagnetic analysis derives RF heat loss under RF duty factor of 3%. Then, temperature distribution and corresponding displacement distribution are derived from thermal and structural analysis respectively under reference temperature of 27℃. Finally, frequency detuning of the tank corresponding to the deformation is derived from electromagnetic analysis. In the analysis, tank wall and endplate materials are assigned as stainless steel and drift tubes and stems are assigned as copper. In addition, cooling channel is assigned as water. For the coolant, flow velocity is assumed as 2.5 m/s. Then, heat transfer coefficient of the cooling channel is derived from Dittus-Boelter equation. [5] The 3D model of the tank is shown in Fig. 1 and heat transfer coefficient of each cooling channel is represented in Table 1. It is noted that heat transfer coefficient of the side cooling channel of DT is assumed as 1/10 of that of the central cooling channel of DT as it does not satisfy turbulent flow condition which is not suitable for applying Dittus-Boelter equation.

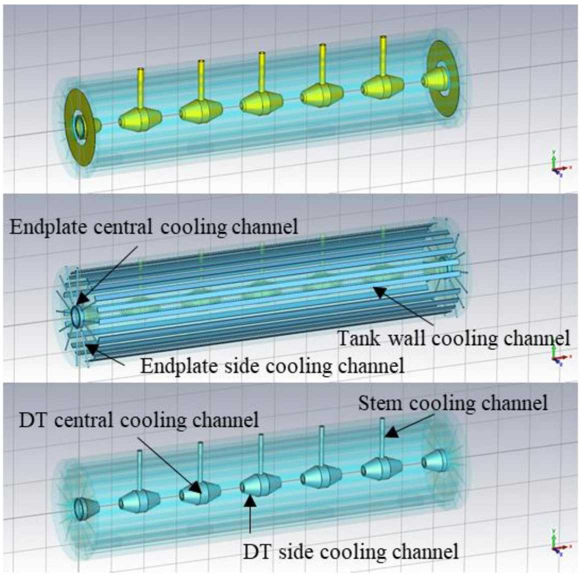

Fig. 1. 3D model of the SDTL tank.

Table I: Heat transfer coefficient of each cooling channel

Cooling channel	Heat transfer coefficient [W/m^{2}K]
Tank wall	10000
Endplate central	6000
Endplate side	8000
DT central	6000
DT side	600
Stem	8000

2.1 Thermal and structural analysis of the tank

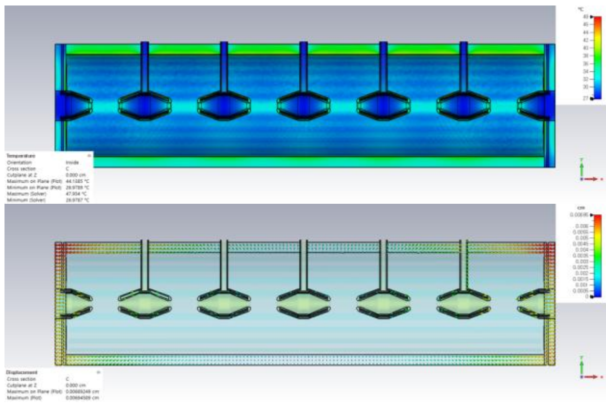

Fig. 2. temperature and displacement distribution of the tank.

Figure 2 shows temperature and displacement distribution of the tank. It is found that tank wall and DT shows temperature increase up to 15℃ and displacement up to 0.007 cm in the upper part of the endplate. Figure 3 shows von mises stress distribution due to thermal deformation. It is found that von mises stress in DTs, stems, tank wall, and endplate are lower than the yield strength of their materials. As a result, it seems that structural integrity of the tank is satisfied under current cooling scheme.

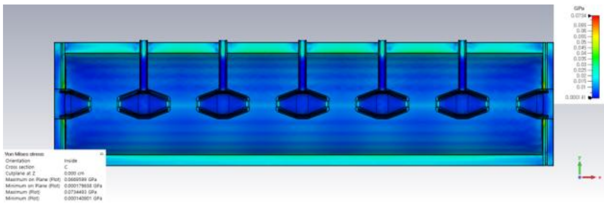

Fig. 3. Von mises stress distribution due to thermal deformation.

2.2 Frequency detuning of the tank

From the displacement distribution, frequency detuning of the tank is obtained from electromagnetic analysis. Table 2 shows frequency detuning of the total tank and that from each part of the tank respectively. It is checked that frequency detuning from the entire tank and sum of each part gives almost same value. Figure 4 shows frequency detuning of the tank according to temperature of the coolant. It is found that frequency sensitivity according to coolant temperature is 6 kHz/℃. As a result, when coolant temperature is lowered by 7℃ compared the reference temperature, frequency detuning can be compensated.

Table 2: Frequency detuning of the tank.

Component	Frequency detuning [kHz]
Total tank	-38.2
First DT + stem	-5.5
Second DT + stem	-5.7
Third DT + stem	-5.8
Fourth DT + stem	-6.0
Fifth DT + stem	-6.1
Tank wall + endplate + half DTs	-9.2
Sum of each part	-38.3

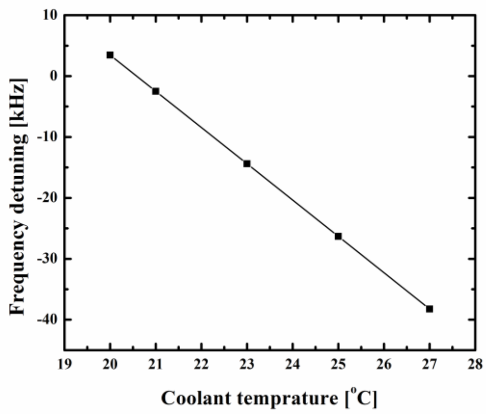

Fig. 4. Frequency detuning of the tank according to temperature of coolant.

Instead of adjusting coolant temperature, movable tuner can be utilized to compensate frequency detuning. In this study, 4 fixed tuners with diameter of 150 mm and 1 movable tuner with diameter of 90 mm are considered. For the reference condition, insertion depth of the movable tuner is 27 mm and insertion depth of fixed tuners are adjusted to achieve resonance frequency of 350 MHz and flat average electric field distribution under 0.5% variation. Figures 5 and 6 show resonance frequency variation and the field distribution according to the insertion depth of the movable tuner respectively. It is found that movable tuner sensitivity is 3.9 kHz/mm. Therefore, from the insertion depth range between 10 mm and 40 mm, compensation range of the movable tuner reaches ±60 kHz. For the frequency detuning obtained in Table 2, 37 mm insertion depth of movable tuner is required to compensate. It is noted that field flatness remains under 1% variation in that insertion depth as represented in Fig. 5.

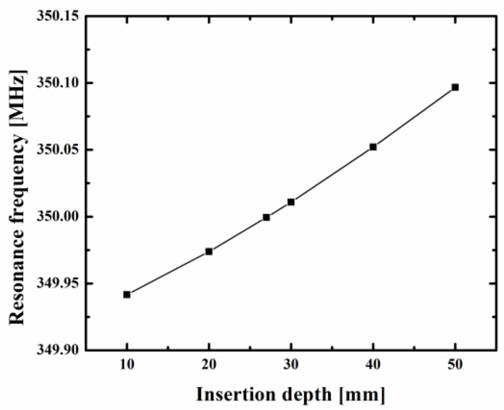

Fig. 5. Resonance frequency variation according to insertion depth of movable tuner.

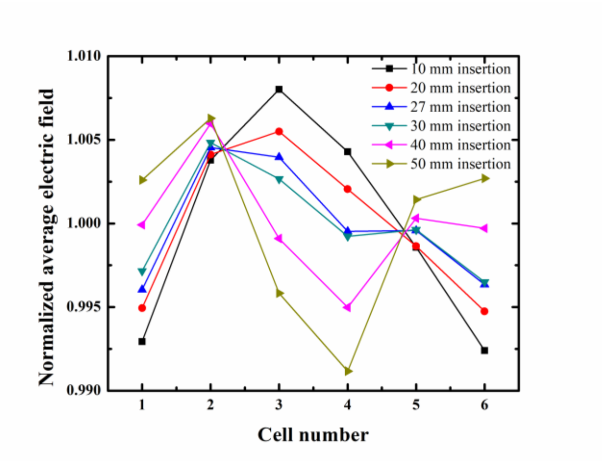

Fig. 6. Average electric field distribution along the cell of the tank according to insertion depth of movable tuner.

3. Conclusions

Utilizing multi-physics analysis, thermal, structural, and electrical characteristics on the SDTL tank during operation are investigated. Under RF duty factor of 3%, von mises stress caused by temperature rise and corresponding displacement represents that structural integrity of the tank is satisfied under current cooling scheme. In addition, frequency detuning of the tank due to thermal deformation is investigated. To compensate the frequency detuning, two options of lowering coolant temperature or utilizing movable tuner are available. For coolant temperature lowering, its sensitivity is found as 6 kHz/℃. For movable tuner insertion, its sensitivity is found as 3.9 kHz/mm. As a result, it is required that coolant temperature is lowered by 7℃ compared to reference temperature or movable tuner is inserted by 37 mm to compensate the frequency detuning.

ACKNOWLEDGEMENT

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