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Impact of the Niobium Cavity Wall Thickness on the Mechanical Performance of the Superconducting Half-Wave Resonator

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1. Introduction

Since 2013, a 100-MeV proton linac has been under operation at Korea Multi-purpose Accelerator Complex (KOMAC) and the accumulated operation time reached 11,062 hours at the end of 2016 [1]. To expand the application field of the 100-MeV proton accelerator, we are planning to develop the generation and the utilization of the secondary particle beam produced by the proton bombardment on the production target and pulsed neutron beam is one of major items under consideration.

Preliminary analysis shows that the neutron yields of about 2.5E13 pps can be obtained on the tungsten target with the average beam power of 1 kW and 100 MeV beam energy. In addition, the neutron yields can be increased by 2.5 times if the incident proton beam energy increases from 100 MeV to 160 MeV. Therefore, we performed basic study to increase the beam energy by adding additional accelerating section at the end of the existing accelerator. The technology of choice for beam energy ramping is SRF (Superconducting Radio-Frequency). The existing accelerator tunnel has room for linac extension up to 160 MeV based on 350 MHz superconducting accelerator.

We chose HWR structure as shown in Fig. 1. The results of the preliminary design study of the HWR with beta of 0.58 can be found in Ref. 2 and the basic design parameters are summarized in Table 1. In this study, we extended the electro-mechanical coupled analysis to investigate the impact of the cavity wall thickness on the mechanical performances of the HWR, such as Lorentz detuning coefficient, frequency sensitivity due to the helium pressure fluctuation, and tuning sensitivity.

2. EM coupled Analysis Method

We used CST MPhysics to perform the electro-mechanical coupled analysis [3]. For the analysis of the Lorents force detuning, the electromagnetic field distribution and radiation pressure load were calculated in the eigen mode solver in CST MWS. Then the radiation pressure load was transferred to the mechanical analysis module in CST MPhysics. By using the CST MPhysics, the cavity wall deformation due to the radiation pressure could be obtained. Finally, we run the CST MWS eigen mode solver again. In this time, the sensivity analysis feature in MWS eigen mode solver was activated. The resonant frequency shift due to the deformation could be calculated by using a perturbation theory without re-meshing the cavity volume with deformed shape.

The sensitivity of the resonant frequency on the helium pressure variation also could be calculated with the similar procedure. The applied load in this case is static pressure due to the liquid helium surrounding the cavity.

Fig. 1. Superconducting half wave resonator.

Table 1. Summary of HWR parameters.

Parameter	Unit	Value
Frequency	MHz	350.0
Optimum beta	-	0.64
Geometric beta	-	0.58
Vacc @ βopt	MV	3.336
Eacc	MV/m	7.212
Ep	MV/m	30.252
Bp	mT	64.392
Ep/Eacc	-	4.195
Bp/Eacc	mT/(MV/m)	8.928
R/Q @βopt	ohm	285.2
G @ 20 nΩ	ohm	123.8
Q_0 @ 20 nΩ	-	6.19E+09
Loss @ 20 nΩ	W	6.38
Leff	m	0.4625

3. Analysis Results

To investigate the cavity wall thickness effect, we followed the procedure as shown in Fig. 2. And described in section 2 in detail. With 1 J stored energy normalization, the maximum radiation pressure was estimated to be about 132.6 Pa as shown in Fig. 3. In the calculation of the RF properties, we don't need to consider the cavity wall thickness. When we perform the mechanical analysis, we should consider the niobium cavity wall thickness as shown in Fig. 4. The material properties needed in the mechanical analysis include the Young's modulus and Poisson's ration at 2 K and we used 110.9 GPa and 0.393, respectively.

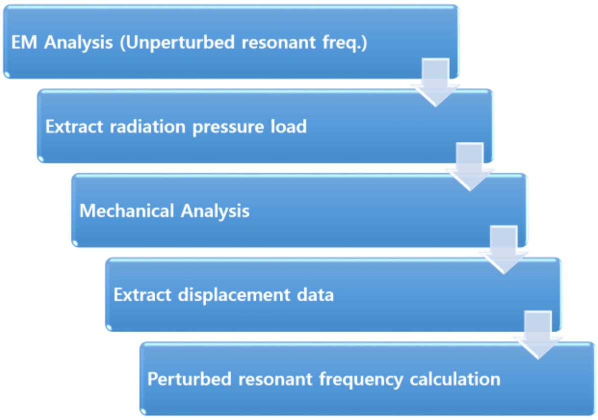

Fig. 2. EM coupled analysis procedure.

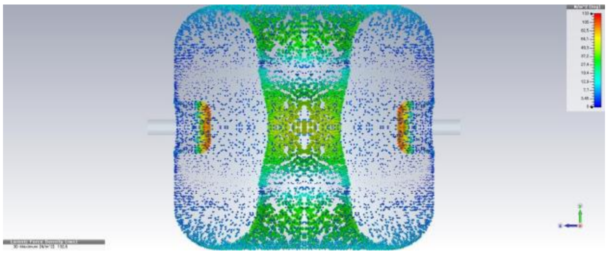
Fig. 3. Radiation pressure load distribution.

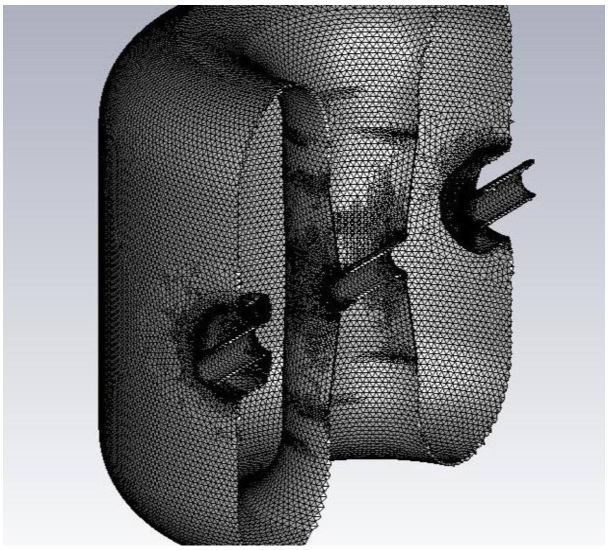
Fig. 4. Mesh view for the mechanical analysis.

Generally, the superconducting HWR wall thickness ranges from 2 mm (as in SARAF original cavity) to about 4 mm (as in FRIB or ESS spoke). We chose 2.5 mm as reference. Mechanical stiffness increases as the thickness increases. But large thickness has disadvantage with respect to the thermal stability, therefore there exists some optimum thickness. We compared the reference case (2.5 mm) and 3.0 mm thickness. The results are summarized in Table 2. Lorentz detuning coefficient decreases from 2.2 Hz/(MV/m)^2 to 1.7 Hz/(MV/m)^2. In contrast, the thickness has little effect on frequency sensitivity to the helium pressure fluctuation.

Table 2. Mechanical performance summary

Wall thickness	Lorentz coefficient	Sensitivity on LHe pressure
2.5 mm	2.2 Hz/(MV/m)^2	5.1 Hz/torr
3.0 mm	1.7 Hz/(MV/m)^2	5.0 Hz/torr

4. Summary

We performed the electro-mechanical coupled analysis to investigate the effect of superconducting HWR wall thickness on the mechanical performance. Lorentz detuning coefficient decreased by 22% as the wall thickness increased from 2.5 mm to 3.0 mm. The sensitivity of resonant frequency on LHe pressure variation was little affected by the thickness increase. The final thickness of the HWR cavity will be determined after considering other effects such as tuning stiffness and thermal stability.

Acknowledgment

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