DESIGN AND ANALYSIS OF SLOW TUNER IN THE SUPERCONDUCTING CAVITY OF RISP*

Myung Ook Hyun, Hoe Chun Jung, Hyung Jin Kim
Rare Isotope Science Project (RISP), Institute of Basic Science (IBS), Daejeon, Korea

Abstract

Superconducting cavity is one of the most complex systems from the view of mechanical engineering, which is installed and operated in the superconducting linear accelerator. In order to operate SC cavity properly and precisely, superconducting cavity needs many sub-systems, including power coupler for applying RF power inside cavity, and liquid helium jacket for cooling cavity until reaching to the superconducting conditions. And, also cavity needs frequency tuning system for adjusting operating frequency when RF frequency of cavity is changed with outer disturbances such as liquid helium fluctuation, mechanical deformation due to vacuum condition of cavity. Generally, this tuning system is called as a tuner. There are two types of tuner, one is slow tuner which operates with motor, and the other is fast tuner which operates with piezo-electric actuator. This paper describes about design process and analysis results about slow tuner.

DESIGN OBJECTIVES

For tuning superconducting cavities, a tuner should generate high force and operate with proper speed. To decide specification of slow tuner, first we setup our tuning target as quarter wave resonator (QWR) type cavity. Next, we consider other tuner's specification for operation conditions of our slow tuner [1]. Table 1 shows the specifications of other research group's tuner [2].

Table 1: Specification of Other Tuners

	CEBAF Upgrade	RIA 0.47	SNS 0.61	TESLA 500
Cavity Frequency (MHz)	1497	805	805	1300
Lorentz Detuning (Hz)	324	1600	470	434
Coarse Range (kHz)	±400	950	±245	±220
Tuning Method	Tension	N/A	Comp.	Tension Comp.

QWR cavity's resonant frequency is 81.25 MHz, comparably lower than other cavities. Therefore, we can setup our target as similar as above specification, because these are higher specification thus we surely can control our cavity with high specification, if we can make our slow tuner satisfying above specification. Consequently, we setup coarse tuning rage as ±100 kHz, and tuning method as compression only due to its easiness and robustness as well.

CONCEPT DESIGN

At the design stage, we first decided some design constraints with cavity designers. Cavity designers want to operate slow tuner along the beam direction, not to other position, because adjusting cavity's inner gap is the most efficient than others. Figure 1 shows concept design of slow tuner for QWR cavity.

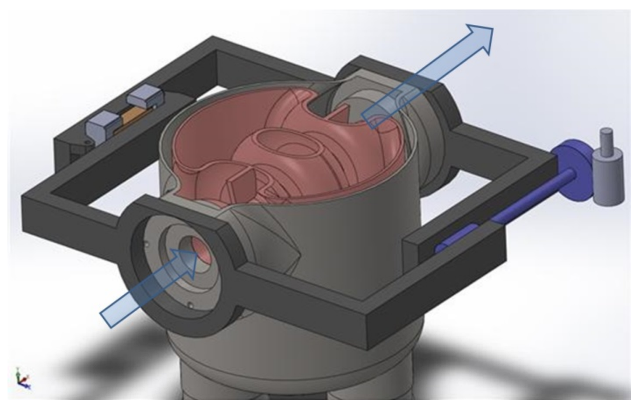

Figure 1: Layout of Slow Tuner for QWR Cavity.

Blue arrow represents the beam direction, and black structure is slow tuner. Right side of slow tuner is worm-worm wheel components which reduce operating speed and increase transferred force. Red structure is cavity and gray structure is liquid helium jacket. From cavity and liquid helium jacket design, cavity's beam port flange is connected with jacket body so that pulling or pushing beam port flange is most effective for tuning resonant frequency of cavity.

There are many tuning mechanisms in other tuners, like simple lever [3], complex lever [4, 5], or compliant mechanism [6]. Through many considerations, we decided to use lever mechanism because it is very easy to operate.

FEM ANALYSIS

QWR Cavity

Determining tuning force, we first analysed strength and elastic range of dressed QWR cavity. Table 2 shows material properties of cavity and liquid helium jacket.

Table 2: Material Properties of QWR Cavity and Jacket

	Niobium @ RT	**Niobium** @ 4.2K	**SS304** @ RT	**SS304** @ 4.2K
Young's Modulus (GPa)	102.7	111.0	199.9	210.3
Poisson's Ration	0.395	0.393	0.270	0.279
Density (g/cm^3)	8.580	8.580	7.916	7.916
Yield Strength (MPa)	48.26	317.2	206.8	344.7

QWR cavity is made of niobium material which is usually used for superconducting products. And liquid helium jacket is made of stainless steel 304L or 316L for enduring cryogenic temperature. By using this data, we carried out structural analysis with finite element method (FEM) [7]. Figure 2 shows QWR cavity and liquid helium jacket assembly with tuner. Using commercial tool, ANSYS mechanical 2014 version, we applied 13,000 N pushing force on the flange end as a loading condition and fixed support condition at the strong-back connection interface as boundary condition.

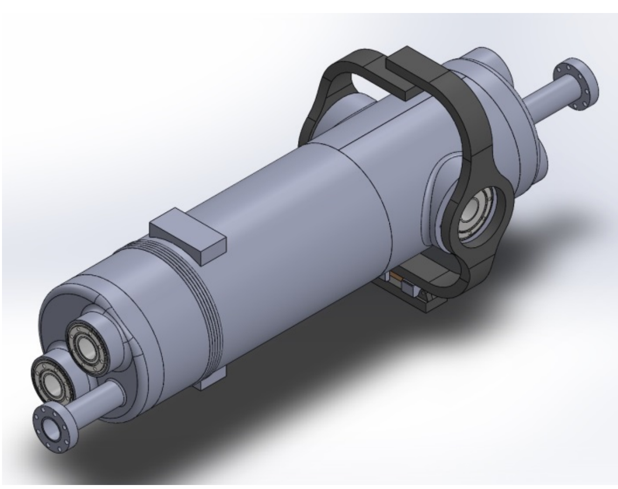

Figure 2: QWR Cavity and Liquid Helium Jacket.

From FEM analysis, we confirmed that structural stress and strain is less than yield strength, both at RT and at 4.2 K conditions. Therefore, we concluded that QWR cavity and liquid helium jacket is designed with proper safety margin.

Lever Arm

From the QWR cavity analysis, we performed structural analysis of slow tuner's lever arm, initial design with FEM. Using commercial tool, Solidworks 2014 version, we applied 6,500 N pulling force at the lever end as the loading condition and only rotation free at the hinge as boundary condition. Figure 3 and 4 shows the Von-Mises stress and strain of slow tuner lever arm.

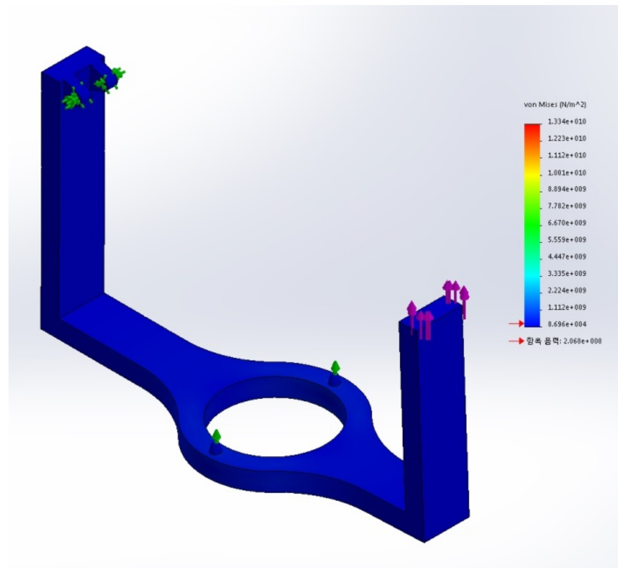

Figure 3: Von-Mises Stress of Tuner Lever Arm.

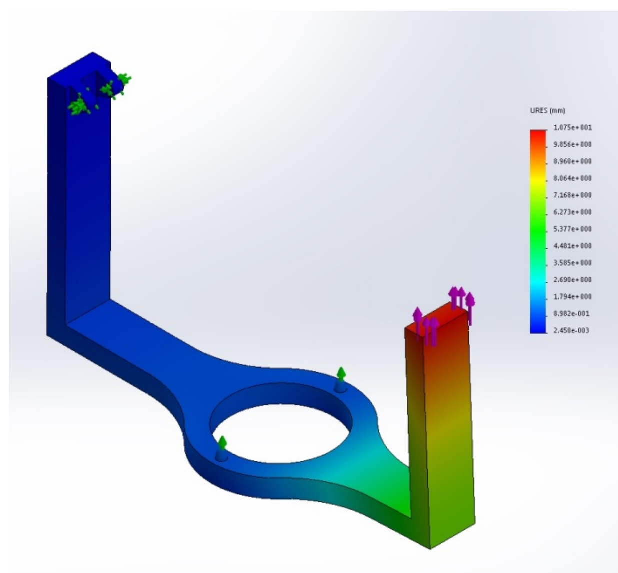

Figure 4: Von-Mises Strain of Tuner Lever Arm.

Through analysis, we found that stress is quite low, 86.9 kPa, so that durability and lifecycle of slow tuner is guaranteed. However, we should modify lever arm designs as satisfying installation space constraints. Due to the narrowness of inner space of vacuum chamber where

ISBN 978-3-95450-142-7

QWR cavity should be installed, lever arm shape should be modified. After changing lever arm shape, we proceeded FEM analysis again. Figure 5 and 6 shows the Von-Mises stress and strain of modified slow tuner lever arm.

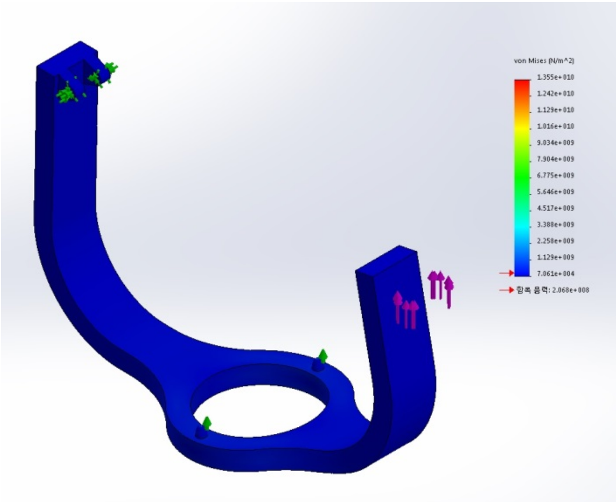

Figure 5: Von-Mises Stress of Modified Lever Arm.

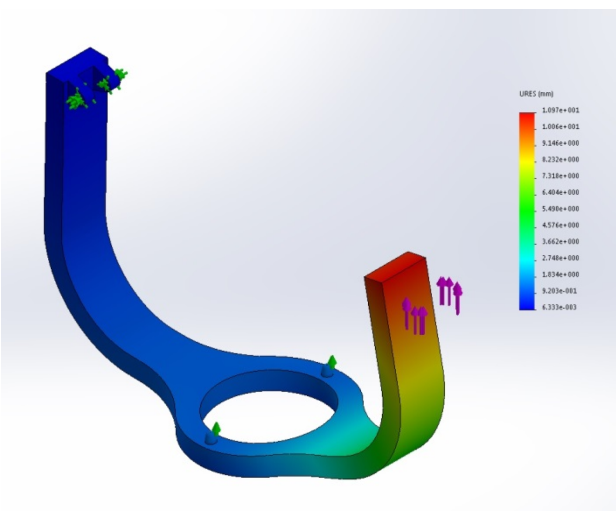

Figure 6: Von-Mises Strain of Modified Lever Arm.

According to FEM analysis, the Von-Mises stress of lever arm decreased to 70.6kPa, about 18.7% less than initial design. Therefore, we concluded that durability and lifecycle of modified lever arm is guaranteed.

CONCLUSION

Through analysis, we concluded that our tuner design is enough to compensate resonant frequency of superconducting cavity as we intended. However, full model of cavity, jacket, coupler, and tuner was not analysed. When every sub-part is finished, we should put them all in together so that we can get a multi-body simulation including low frequency resonance.

ACKNOWLEDGMENT

This work was supported by the Rare Isotope Science Project (RISP) of Institute of Basic Science (IBS) funded by the Ministry of Science, ICT and Future Planning (MSIP) and the National Research Foundation (NRF) of the Republic of Korea under Contract 2013M7A1 A1075764.

REFERENCES

[1] H. Padamsee, RF Superconductivity: Science, Technology, and Applications, WILEY-VCH, ISBN 978-3-527-40572, 2009.
[2] J. Delayen, Tuning System, USPAS, June, 2008.
[3] T. Ries et al, A Mechanical Tuner for the ISAC- Quarter Waver Superconducting Cavities, Proceedings of the 2003 Particle Accelerator Conference, 2003.
[4] E. F. Daly et al., Testing of the New Tuner Design for the CEBAF 12 GeV Upgrade SRF Cavities, Proceedings of 2005 Particle Accelerator Conference, Knoxville, Tennessee, USA, 2005.
[5] J. Rank et al., Design Consideration for the Mechanical Tuner of the RHIC Electron Cooler SRF Cavity, Proceedings of 2005 Particle Accelerator Conference, Knoxville, Tennessee, USA, 2005.
[6] Carlo Pagani et al., Improvement of the Blade Tuner Design for Superconducting RF Cavities, Proceedings of 2005 Particle Accelerator Conference, Knoxville, Tennessee, USA, 2005.
[7] O.C.Zienkiewicz et al., The Finite Element Method for Solid and Structural Mechanics, Sixth Edition, ISBN 0-7506-6321-9, 2005.