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MECHANICAL DESIGN OF SINGLE SPOKE RESONATOR TYPE-2 (SSR2) SUPERCONDUCTING CAVITY FOR RISP*

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Abstract

Superconducting linear accelerator and many beam experimental devices for the future of basic science research in Korea are being made and prepared for installation in Sindong linac tunnel north side of Daejeon, Korea. The key components of superconducting linac are the superconducting cavities and RISP linac has four types of superconducting cavities such as quarter-wave, half-wave, and single spoke resonator type-1 and 2. In this paper, we introduce about the initial RF/EM design of single spoke resonator type-2 (SSR2) superconducting (SC) cavity, and explain about mechanical design. Afterwards, we analyze mechanical design parameters of SSR2 SC cavity using ANSYS 18.0 structural solver and material properties of RRR 300 pure-niobium and stainless steel.

INTRODUCTION

From 2011 to now, RISP proceeded enormous research and development of superconducting linac and experimental devices. In our group - Accelerator System Team (AST) – four types of SC cavity, RF coupler, tuner, and cryomodule are designed, fabricated, and tested in the Munji SRF test facility. At the low energy linac region, quarter-wave (QWR) and half-wave (HWR) resonator will be installed, and single spoke resonator type-1 (SSR1) and type-2 (SSR2) also will be installed into the high energy linac region [1]. Between 2012 and 2014, we proceeded first prototyping of every SC cavity types and tested using different SRF facility like TRIUMF, Canada, or Cornell Univ., USA. Unfortunately, we didn't reach our target performance of both SSR1 and SSR2 SC cavity. Therefore, we tried to find out proper design of SSR1 SC cavity with the collaboration of TRIUMF, Canada. Based on the MOU and general contracts, TRIUMF invented a new concept of SSR1 SC cavity called 'Balloon Variant' [2,3]. TRIUMF also proceeded fabrication with PAVAC and 4K/2K cold test using their test facilities [4]. The essential advantage of balloon variant SC cavity shape is the suppression of multipacting effects. We decided to apply same balloon variant concept to the SSR2 SC cavity after SSR1 2K cold test was satisfied our expected performances.

SSR1/2 SPECIFICATIONS AND RF DESIGN

Table 1 shows the design specifications of SSR1/2 SC cavity for RISP. For satisfying our high energy SC linac beam lattice, we should evaluate our design specifications.

Figure 1 shows the SSR2 RF volume design for EM simulations. Balloon variant concept was applied same as SSR1 due to its high suppression effect for multi-pacting.

Table 1: Design Specifications of SSR1/2

	Unit	SSR1	SSR2
Operating Frequency	MHz	325	
Beta		0.3	0.51
Operating Temperature	K	2.05	
Q Factor		>5E9	
Epeak	MV/m	35	
Vacc	MV	>2.4	>4.1
df/dp	Hz/mbar	<10	
Beam bore	mm	50	
Pressure Envelope @ 300K	bar	2	
Pressure Envelope @ 5K	bar	5	

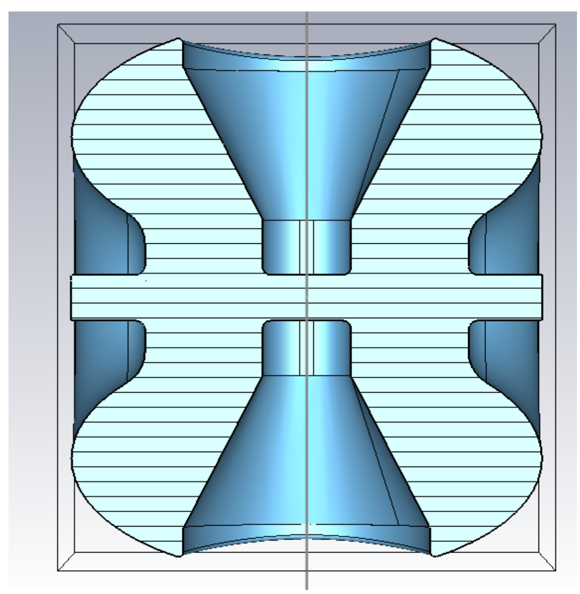

Figure 1: RF volume design done by RF engineer.

With this shape, RF engineer proceeded multi-pacting simulation with CST PIC-solver code, and Fig. 2 shows that the multi-pacting is reduced comparing with RISP SSR2 first prototype and modified RISP SSR2 with double radius corners from the ideation of FNAL [5].

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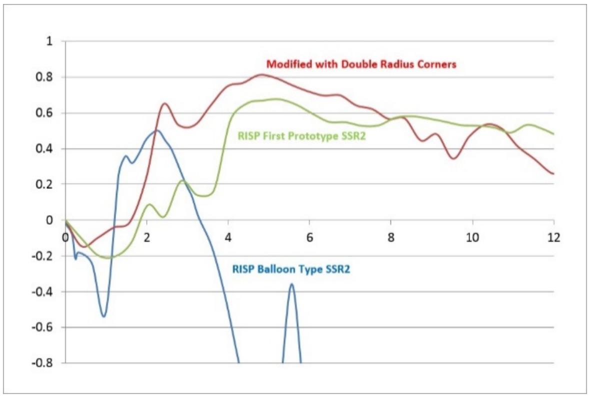

Figure 2: Multi-pacting simulation results.

With some considerations about fabrication capability and peak magnetic field, RF volume design of SSR2 SC cavity was finalized.

STRUCTURAL ANALYSIS

From the initial RF design of SSR2 SC cavity, the mechanical design was proceeded. First of all, we should setup the material properties of SC cavity. In our project, we usually use RRR 300 pure niobium sheet for cavity and stainless steel(STS) 316L as liquid helium jacket(vessel) outside of SC cavity. Table 2 shows the material properties of RRR 300 pure niobium and STS 316L. We choose the sheet thickness of pure niobium and STS as 3mm, which are same with QWR and HWR.

Table 2: Material Properties of Pure Niobium and Stainless Steel 316L

	Unit	RRR300 Niobium	STS 316L
Young's Modulus	GPa	107	193
Poisson's Ratio		0.36	0.25
Density	g/cm^3	8.56	7.99
Tensile Strength	MPa	134	483
Yield Strensth	MPa	51	170
Allowable Stress	MPa	34	113

Tensile strength/3.5 or yield strength/1.5 should be chosen as allowable stress so that niobium allowable stress is 34 MPa and STS316L allowable stress is 113 MPa. We applied these properties into the ANSYS 18.0 WB project file before structural analysis [6]. Figure 3 shows the initial shell design exploded view of SSR2 SC cavity.

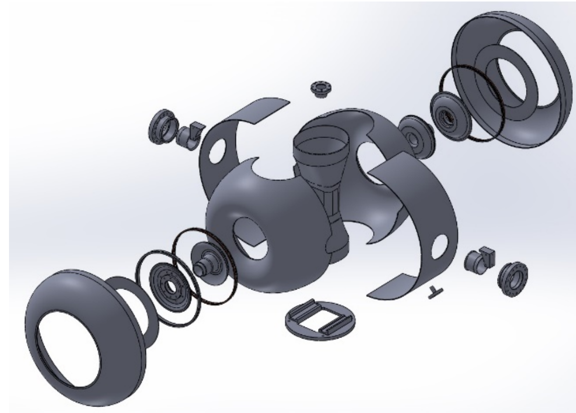

Figure 3 : Exploded view of initial SSR2 SC cavity.

Initially SSR2 SC cavity had no reinforcements so that we added the reinforcement after first structural analysis. For more realistic structural analysis we applied liquid helium jacket with STS316L material. Figure 4 and 5 shows about the difference of spoke deformation between without and with spoke stiffeners. We used ANSYS 18.0 Mechanical WB code for the structural analysis of SSR2 SC cavity.

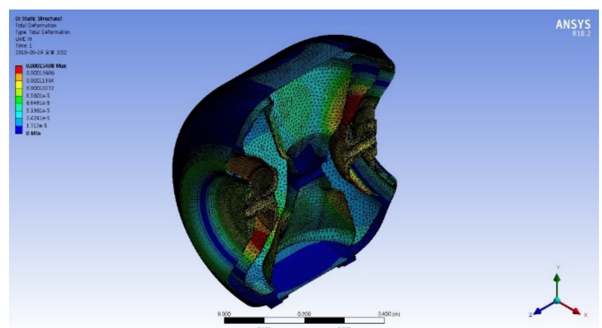

Figure 4 : Deformation shape without Spoke Stiffeners.

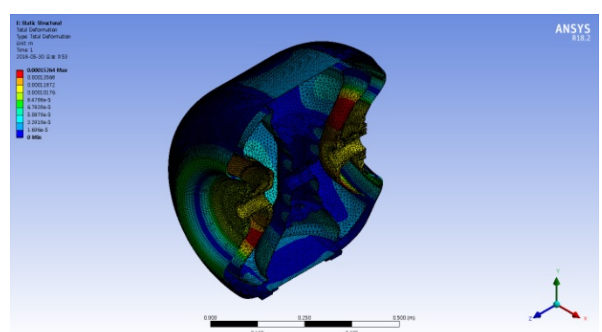

Figure 5 : Deformation shape with Spoke Stiffeners.

For intial structural analysis, we applied rough mesh size as 5mm which is comparably coarse but useful to estimate the tendency of deformation and stress with reducing calculation resources and time. We applied 1.3 bar liquid helium pressure between SSR2 SC cavity and liquid helium jacket for the boundary conditions.

As we expected, deformation around spoke is reduced after applying spoke stiffener. The spoke stiffeners are attached to both side - upper and lower - for avoiding stress

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asymmetric shape. We should find optimal position of spoke stiffener in the further research.

Also, we should apply the transition ring between SC cavity and liquid helium jacket for tuning the cavity by pressing and releasing the beam port flanges. Figure 6 shows the deformation of SSR2 SC cavity with spoke stiffeners and transition ring which interconnected one side of SC cavity and adjacent side of liquid helium jacket. As shown in figure, attached side deformation is comparably reduced with that is shown in Fig. 5.

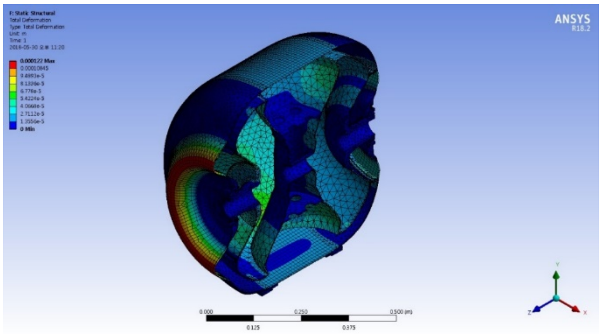

Figure 6 : Deformation shape with Spoke Stiffeners and Transition Ring.

For more robust design, we applied helium pressure up to 2 bar on the SSR2 SC cavity outside surface. With this pressure, maximum deformation of initial shell design is more than 0.2 mm and maximum stress was almost 103 MPa. To avoid the large stress and deformation, we designed the shell stiffener as Fig. 7. This figure shows the double-ring stiffeners which is already applied to the previous SSR2 SC cavity model at 2016 [1], but the composition is changed from niobium to niobium-copper with TIG welding.

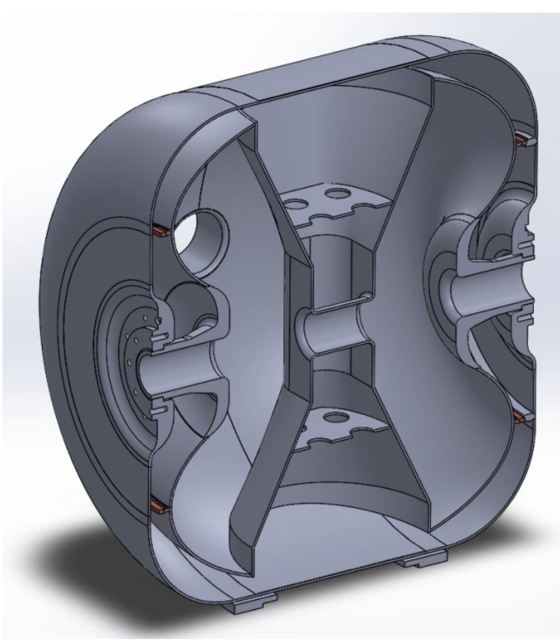

Figure 7 : Nb-Cu Stiffener Ring attached to SSR2 Shell Front and Rear Side.

MODAL ANALYSIS & INTERFACES

For checking the vibration disturbance we should check the natural frequency of SSR2 SC cavity as well. We used ANSYS 18.0 Mechanical WB modal analysis solver for analysing natural(eigen) frequencies at low frequency range. Figure 8 shows the resonance map of SSR2 SC cavity as well.

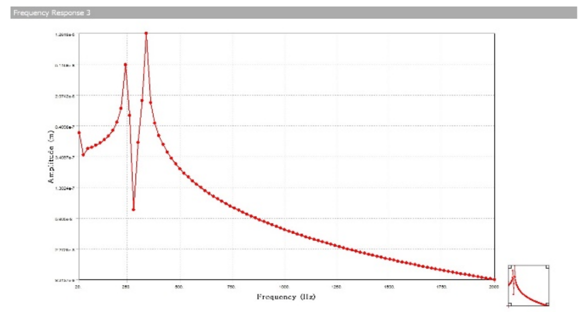

Figure 8: Resonance Map of Dressed SSR2 SC Cavity.

With this figure, we can see that there is some resonance possibility between 240Hz and 250Hz (simulation results was 245.45Hz) with the front beam flange disturbance and fixed point at the spoke beam tube as boundary conditions. Figure 9 shows the deformation and stress shape of SSR2 SC cavity with 245.45Hz resonance.

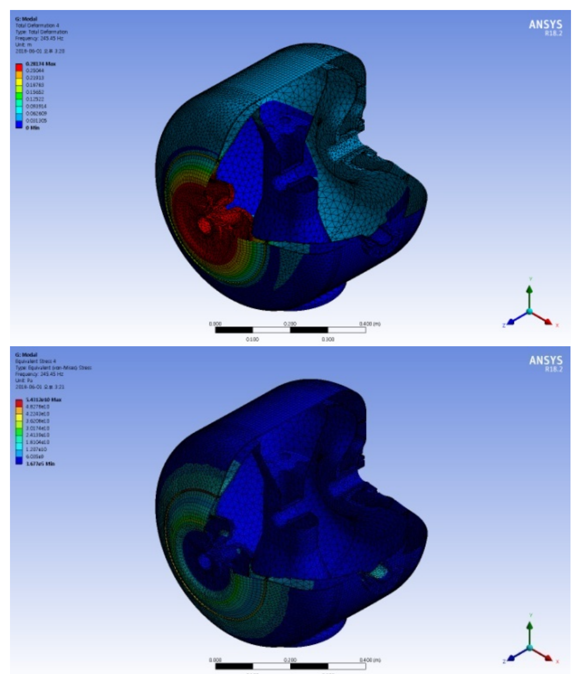

Figure 9: Deformation(a) and Stress(b) shape of SSR2 SC cavity with 245.45Hz resonance.

Considering about general external disturbance due to the motor rotation speed frequency such as 50Hz or 60Hz, 240Hz is same as 4 times of 60Hz and 250Hz is same as 5 times of 50Hz, so that the resonance can be happened with this natural frequency. Therefore, we should consider the

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reinforced structure for avoiding resonance. We will investigate the robust design for solving resonance issues at the future works. Furthermore, we will apply different type of external disturbance to the dressed SSR2 cavity as well.

For the consistency of interfaces of SSR2 SC cavity and those of SSR2 SC cavity, we applied the same type and size of flange connection. Figure 10 shows the interfaces of SSR2 SC cavity and Table 3 shows about the key dimensions.

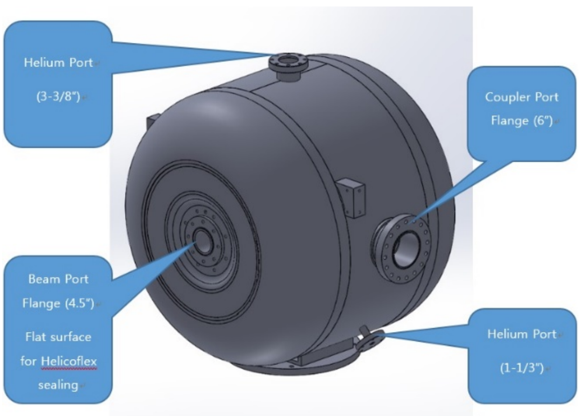

Figure 10: SSR2 Cavity Interface.

Table 3: Key Dimension of SSR2 SC Cavity

	SSR1	SSR2
Outer Diameter	568mm	612mm
Iris-to-iris Length	190mm	320mm
Beam Flange Length	400mm	538mm
Stiffener Diameter	327mm	345mm
Spoke Stiffener Length	376mm	200mm
Coupler Ports Width	718mm	716mm
Stiffener Thickness	5mm	5mm
Jacket Diameter	590mm	626mm
Jacket Length	400mm	546mm
Jacket Thickness	3mm	3mm

We are now under researching about our design parameters of SSR2 SC cavity like end curvature radius of helium jacket and width of stiffener ring. The main purpose of mechanical design parameter is to satisfy the design performance like df/dp or target frequency. Another reason of mechanical design parameter is to follow pressure vessel code [7] so that we guarantee the safety of our SC cavity with operating circumstances. With this purposes, we setup the design objectives as follows:

- minimize df/dp (STB)
- minimize stress (STB)
- frequency target is 325MHz (NTB)

First of all, we will proceed our structural analysis with this objectives and all design parameters. After analyzing parameter sensitivity and parameter correlation, we will select important parameters and make an experimental table with the design of experiment (DOE) method.

CONCLUSIONS

According to the mechanical design and analysis, we can find a proper shape of SSR2 as above. Our institute already contracted with domestic company for the prototyping of SSR2 with this design. We will finalize our SSR2 engineering design after many discussions and considerations with the contractor soon. Also, we can show the fabrication process and the test result in the future.

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REFERENCES

[1] H.J. Kim, H.C. Jung, W.K. Kim, "Progress on Superconducting Linac for the RAON Heavy Ion Accelerator", in Proceedings of IPAC2016, Busan, Korea, 2016, paper MOPOY039, pp. 935-937.

[2] Z. Yao, R.E. Laxdal, V. Zvyagintsev, "Balloon variant of Single Spoke Resonator", in Proceedings of SRF2015, Whistler, Canada, 2015, paper THPB021, pp. 1110-1114.

[3] Z. Yao, R.E. Laxdal, B. Waraich, V. Zvyagintsev, R. Edinger, "Design and Fabrication of Beta=0.3 SSR1 for RISP", in Proceedings of LINAC2016, East Lansing, MI, USA, 2016, paper MOPLR041, pp.226-228.

[4] RISP SSR1 Pre-Fabrication Design Report, written by TRIUMF SRF Group and PAVAC, July 2016.

[5] Gennady Romanov, Paolo Berrutti, Timergali N. Khabiboulline, "Simulation of Multipacting in SC Low Beta Cavities at FNAL", in Proceedings of IPAC2015, Richmond, VA, USA, 2016, paper MOPMA018, pp.579-581.

[6] ANSYS2018, www.ansys.com

[7] The American Society of Mechanical Engineers ASME Boiler and Pressure Vessel Code, Section II – Part D, 2000.