

Current Status of Single Spoke Resonator Type-1 Pre-production at RAON

Giyeol Han*, Junyoung Yoon, Heejin Do, Jangwon Han, Youngkwon Kim and Yong-Sub Cho
Institute for Rare Isotope Science, Institute for Basic Science (IBS), Daejeon 34000, Korea

*Corresponding author : gyhan@ibs.re.kr

***Keywords :** superconducting cavity, SRF accelerator, single spoke resonator

1. Introduction

The Rare isotope Accelerator complex for ON-line experiments (RAON) at Daejeon, Korea, whose construction project started in 2011, is the superconducting linac. In 2022, the first phase of the construction of the low-energy linac for the rare isotope (RI) accelerator was completed, and low-energy rare isotope beams up to 18 MeV for uranium are now being provided to external experimental users. The ultimate goal of the project is to build a high-energy linac capable of delivering 200 MeV beam power for uranium. At present, the research and development for the high-energy linac is in progress. For the high-energy linac, two types of single spoke resonators (SSR) are currently under development. In the front section of the linac under development, a balloon-shaped SSR1 is employed to accelerate heavy ion beams up to 0.32 times the speed of light ($\beta = 0.32$). In the rear section, cylindrical SSR2 are used to further accelerate the beams up to $\beta = 0.5$. Upon completion, RAON will represent the world's first accelerator that integrates both the Isotope Separation On-Line (ISOL) method and the In-Flight separation (IF) method, providing a unique platform for advancing nuclear science. This achievement is expected to make significant contributions to the discovery and study of RI that have not been accessible with existing facilities. This paper reports the current status of SSR1 cavity pre-production with change of jacket material, mechanical design and frequency tuning strategy.

2. Methods and Results

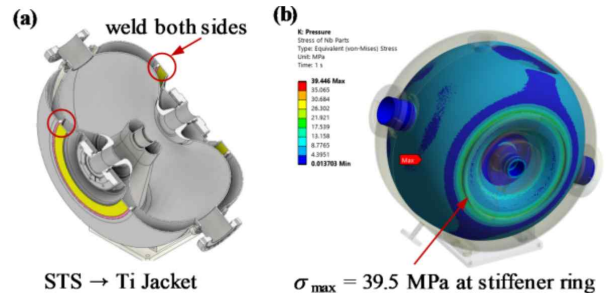
2.1 Mechanical Design

Table I lists the desired RF parameters of SSR1. The RF parameters are almost the same as our past prototype SSR1 [1]. Considering the magnetization of STS material, difference of thermal expansion coefficient, the He jacket material is changed to Titanium Gr. 2 from STS. However, low elastic modulus of titanium compare to the STS reduces the entire stiffness of cavity structure. In the current mechanical design, finite element simulation predicts that under cavity vacuum conditions, stresses exceeding the allowable limit occur near the stiffener ring due to Ti jacketing. Although these stresses remain below the yield strength and are generally not problematic, they could, during testing or over the long term, cause slight

deformations that may lead to a frequency shift. To deal this problem, the stiffener rings on both sides (Fig. 1a) are welded to Ti jacket and reduced the stress concentration on stiffener ring (Fig. 1b).

Table I: RF parameters of SSR1

Parameters	Value	Unit
Frequency	325	MHz
β_{opt}	0.32	—
Beam aperture	50	mm
L_{eff}	298.2	mm
G	92.2	Ω
R/Q	233	Ω
V_{acc}	2.36	MV
E_{acc}	7.9	MV/m
E_{peak}	32.4	MV/m
B_{peak}	54.5	mT



STS → Ti Jacket $\sigma_{max} = 39.5$ MPa at stiffener ring
Fig. 1. (a) Section view of SSR1 cavity and (b) stress analysis results for cavity vacuum condition.

2.2 Bare Cavity Production

The cavity half shell is fabricated by deep drawing process from the high RRR (~ 300) niobium sheet. The pre-forming test with the copper sheets confirmed that the minimum thickness of formed shell over 2.6 mm. The minimum thickness based on the ASME BPVC is 2.5mm. Thereafter, the beam port cup machined from Nb rod is welded to half shell. Before clamp-up test, the stiffener rings are welded to the cavity outer surface to reduce the shift of frequency measured at clamp-up test and final welding. To minimize the cavity deformation, 60% of total circumference of stiffener ring are stitch welded. To remove dents generated during the pressing process and to maximize the smoothness of the RF surface, the entire shell surface, the beam cup, and the weld areas are all polished.



Fig. 2. Each part consisting the single spoke resonator cavity

2.3 Clamp-up test

The production tolerance of the cavity induces a frequency shift from the desired target frequency. Therefore, the frequency is measured by a clamp-up test adjusted by mechanical trimming. Unlike QWR or HWR cavities [4], clamp-up testing of an SSR cavity is more difficult due to its many unwelded components and complex geometry.

Fig. 3 shows two strategies for frequency adjustment through mechanical trimming. The shell trimming method applied to the past SSR1 prototyping. However, this approach induces a misfit at the collar-shell interface, which leads to poor electron beam welding quality (Fig. 4). On the other hand, machining the beamcup alters the geometry of the RF surface where the E -field is relatively high, but provides higher frequency sensitivity [3]. Moreover, for the vertical test with the cavity fabricated using this tuning method, no detectable X-ray was observed even at high E_{acc} [2], so we adopted the latter method.

The target frequency was determined as 323.8 MHz considering the weld deformation, BCP, vacuum evacuation, 2K cooldown (Table II). The frequency shift by 2K cooldown was calculated by numerical simulation. The thermal contracted shape of cavity is calculated by thermal - mechanical simulation with ANSYS and the EM simulation was performed using deformed shaped. To minimize the frequency perturbation due to the pick-up antenna, the antenna length is optimized as 96mm.

Fig. 5 shows the clamp-up test, in which Teflon bar was used to align the beam port and spoke. Table III presents the measured frequencies under various conditions during the clamp-up test. The main concern of clamp-up test is to ensure a consistent Δf value after final welding. Since frequency reproducibility was confirmed under the condition where bolts were tightened with the specified torque and copper tape was applied, this condition was used for the clamp-up test. Any deviation from the target frequency caused by

welding will be corrected through a detuning process that plastically deforms the cavity.

Table IV shows the frequency sensitivity with respect to beamcup (l_{BP}) machining after establishing the clamp-up test conditions. The measured sensitivity was $df/dl_{BP} = 500$ kHz/mm, which was consistent with the simulation results (470 kHz/mm). The cavity is currently under the electron beam welding process, being close to the clamp-up target frequency.

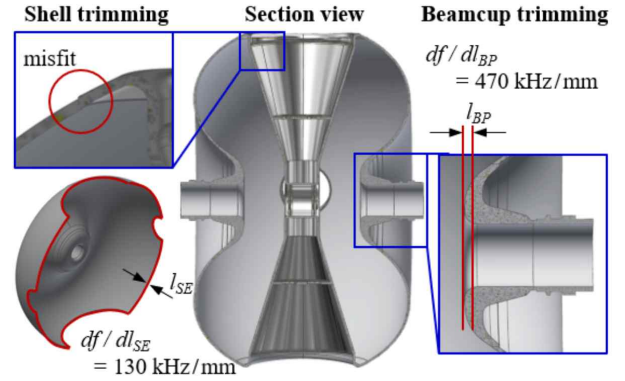


Fig. 3. Shell and beamcup trimming at frequency tuning process

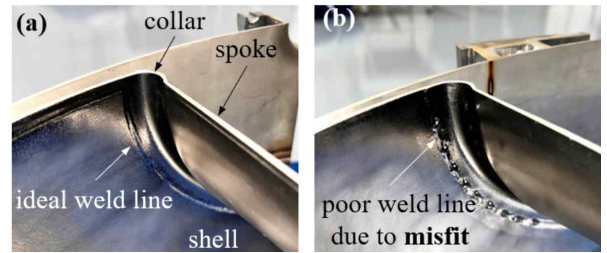


Fig. 4. (a) ideal and (b) poor weld bead at shell - collar interface of SSR2 cavity

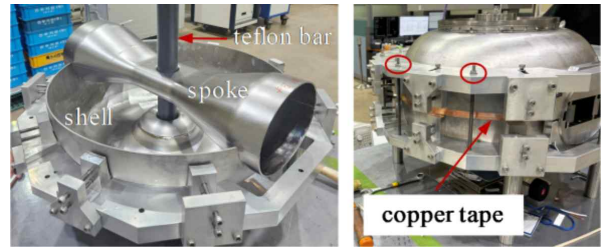


Fig. 5. Clamp-up test of balloon type SSR1 cavity

Table II: RF parameters of SSR1

process	Δf [MHz]	f [MHz]
Tuner	- 0.07	325.00
2K cooldown	+ 0.84	325.07
vacuum evacuation	+ 0.09	324.23
BCP (150um)	- 0.002	324.14
Spoke - shell welding	+ 0.16	324.14
Spoke - collar welding	+ 0.2	323.98
Half shell welding	- 0.04	323.78
Clamp-up test		323.82

Table III: Effect of clamp-up condition on cavity frequency

Cavity #	Clamp-up condition	f [MHz]
3	Cu tape	322.8
3	Cu tape, 50 kgf mm torque	323.0
3	Cu tape, 60 kgf mm torque	323.0

Table IV: Frequency change due to beamcup trimming

Cavity #	l_{BP} [mm]	f [MHz]
3	0	323.0
3	1.5	323.75

3. Conclusions

In this study, the fabrication of SSR1 cavity and the frequency tuning strategy under development for the 2nd-phase high-energy linac of the RAON were reported. The He jacket material was changed to Ti, and the mechanical design is modified. Each part of the cavity was fabricated, and the clamp-up test conditions were established to ensure frequency reproducibility. The frequency sensitivity by beam cup machining was found to be in good agreement with the simulation results.

Acknowledgement

This work was supported by the National Research Foundation of Korea(NRF) funded by Ministry of Science and ICT(RS-2022-00214790)

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