DESIGN AND FABRICATION OF BETA=0.3 SSR1 FOR RISP*

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Abstract

A 325MHz β=0.30 balloon variant of single spoke resonator, which was proposed to suppress multipacting around operational gradient, was chosen as the prototype cavity of SSR1 for Rare Isotope Science Project (RISP). It was also demonstrated to achieve good RF and mechanical properties by geometry optimization for both cavity and helium jacket. The details of RISP SSR1 design will be reported in this paper, accompanying with some particular considerations of fabrication for this new member to the spoke family.

INTRODUCTION

RISP has been proposed as a multi-purpose accelerator facility at the Institute for Basic Science (IBS), Korea, for research in atomic and nuclear physics, material science, bio and medical science, etc. It can provide various energy beams of exotic rare isotopes up to uranium. [1] The facility consists of three independently phased superconducting linacs. The high energy section SCL2 of the driver linac uses two types of 325MHz single spoke resonators with geometry β at 0.30 and 0.51. It accepts beam at an injection energy of 18.5MeV/u and accelerates to 200MeV/u for uranium.

A prototype cavity of the lower β single spoke resonator SSR1 has been designed at TRIUMF under collaboration with IBS, and is being fabricated at PAVAC. The cavity, shown in Figure 1, is termed the balloon variant due to the conformal shape of the outer conductor that obviates the need for a central spool. The balloon variant is proposed to suppress multipacting in the accelerating gradient range of several MV/m by pushing the secondary electron trajectories to the unstable resonance regime. [2] It also provides a more inherently robust mechanical structure.

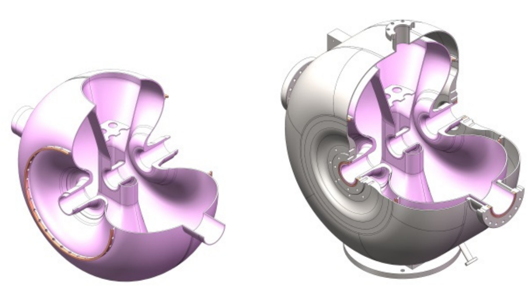

Figure 1: Cross sections of bare cavity (left) and jacketed cavity (right) of RISP SSR1.

SSR1 is designed to operate in continuous wave (CW) mode at 2K with thepeak electric field limited by specification to ≤35MV/m to reduce the likelihood of field emission. The design specifications are listed in Table 1.

Table 1: Design Specifications of RISP SSR1.

Parameters	Value
Operating frequency	325 MHz
Geometry β	0.30
Operating temperature	2K
Q_0	$>5\times10^9$
E_{peak}	35 MV/m
V_{acc}	>2.5 MV
df/dp	<10 Hz/mbar
Frequency tuning range	±100 Hz
Q_{ext}	8×10^6
RF bandwidth	40 Hz
Beam aperture	50 mm
Pressure envelop at 300K	2 bar
Pressure envelop at 2K	5bar

RF DESIGN

The operational E_{peak} is limited at 35MV/m as per specification, to avoid field emission and provide stable operation. Minimizing E_{peak}/E_{acc} is a main goal of the RF design to achieve higher cavity gradient and energy gain for the beam.

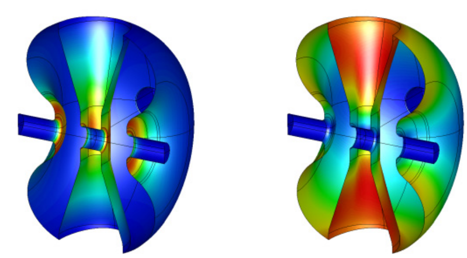

Figure 2: Electric (left) and magnetic (right) field distribution of SSR1.

Geometry Optimization

The major difference of the balloon SSR1 to the conventional spoke resonators is the shape of outer conductor. It is proposed for multipacting suppression, which is mostly effective on the minimum electric field regions. On the other hand, these areas do not affect cavity RF parameters so much as that of the spoke bar. The geometry optimization is similar to conventional spoke designs. The optimization around the beam aperture region is to minimize E_{peak}, while that around the spoke base is to minimize B_{peak}. Geometry factor and R/Q are dependent on the ratio of the inner and outer conductor's dimensions. An elliptical spoke base is chosen to make uniform the magnetic field distribution around the perimeter, which narrows the width of the lowest order multipacting barrier. [2] It decreases the peak magnetic field as well.

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The EM field distributions are shown in Figure 2, and the optimized RF parameters are listed in Table 2.

Table 2: RF Parameters of RISP SSR1.

Design Parameters	
Frequency	325 MHz
Geometry β	0.30
Geometry factor	93 Ω
R/Q	233 Ω
E_{peak}/E_{acc}	3.84
B_{peak}/E_{acc}	6.07 mT/(Mv/m)
Operational Parameters	
E_{peak}	35MV/m
E_{acc}	9.11MV/m
V_{acc}	2.52MV
B_{peak}	55.3mT
U	13.4J

Multipacting

Multipacting is an issue of single spoke resonators [3] and limits cavity performance in some cases. The balloon geometry is proposed to suppress multipacting barriers around the operational gradient. It narrows the width of barriers and pushes them to lower field values. [2] The predicted multipacting of RISP SSR1 is shown in Figure 3 with secondary electron growth rate. All barriers are in the gradient range of 0.5MV/m to 3MV/m, and far away from the operational gradient of 9.1MV/m.

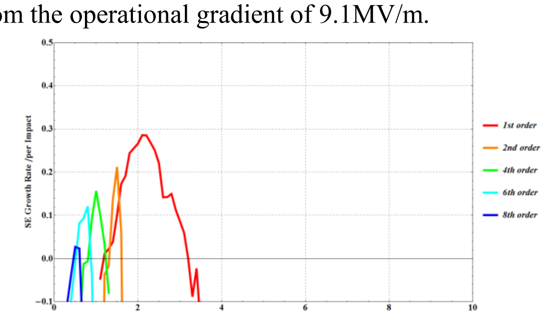

Figure 3: Predicted multipacting barriers of SSR1.

MECHANICAL DESIGN

The cavity mechanical design was done with the helium jacket included, and the model is shown in Figure 1. Stainless steel (SS) 316L is chosen for the helium jacket and cavity flanges. SS flanges are brazed to RRR niobium via a copper interface. One of the ring stiffeners on the half cells is connected to the helium jacket via a copper ring, while the other is floating. A 5/8” outer diameter (OD) helium inlet port is located at the right bottom angled 45˚ away from the RF port, and a 2” OD outlet port is on the top. The cavity support flange and alignment mounts are also attached to the jacket.

Pressure Sensitivity

Low pressure sensitivity is required to reduce the cavity frequency fluctuation due to helium pressure fluctuation in CW operation. The frequency sensitivity, df/dp, is minimized by allowing compensating deformations in the rf surface. It promises df/dp close to 0 Hz/mbar, and keeps the cavity flexible for frequency tuning as well.

Helium pressure is applied in the helium space, which pushes the jacket out, while squeezing the cavity in. Consequently, the helium jacket has an obvious influence on df/dp. In addition, one ring stiffener is attached to jacket, while the other is detached. The deformation of each half cell can be separately controlled, and be designed to compensate each other. The df/dp optimization focuses on the jacket geometry instead of the cavity, which is optimized for RF.

In case of a free beam pipe flanges condition, the big fillets connecting the end plates and jacket cylinder, and the transition parts of center cones on the end plates are optimized. The deformation of the optimized model under 1bar pressure is shown in Figure 4. The beam port on the attached side is stretched out, and that on the detached side is squeezed in. The flat transition part on the jacket is left as much as possible to provide enough flexibility for tuning. As for the fixed beam pipe flanges condition, plate stiffeners with holes are added to the spoke on both ends. These add rigidity to the spoke to minimize df/dp. Pressure sensitivities of -1.6 Hz/mbar for free beam pipe and +1.5 Hz/mbar for fixed condition are obtained.

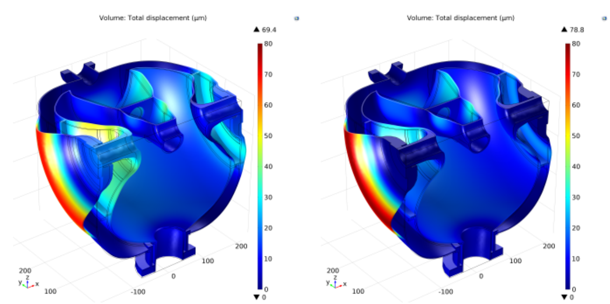

Figure 4: Cavity and jacket deformation under 1bar pressure load in helium space. Left: beam port flange free. Right: beam port flange fixed.

Some major mechanical parameters, including pressure sensitivity, Lorentz force detuning (LFD) coefficient, frequency tuning sensitivity and tuning force, are listed in Table 3.

Table 3: Mechanical Parameters of RISP SSR1.

Parameters	Value
df/dp (beam pipe free)	-1.6 Hz/mbar
df/dp (beam pipe fixed)	+1.5 Hz/mbar
LFD (beam pipe free)	-8.7 Hz/(MV/m)^2
LFD (beam pipe fixed)	-1.4 Hz/(MV/m)^2
Tuning sensitivity	467 kHz/mm
Tuning sensitivity	32.7 kHz/kN
Tuning force (±100kHz)	6.1 kN
Tuning stroke (±100kHz)	0.43 mm
Tuning stress	6.5 MPa/kN

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Pressure Vessel Analysis

The jacketed SSR1 is designed as a pressure vessel considering ASME guidelines. Since the cavity shapes and materials are non-standard, the analysis follows the practical approach [4] to cavity design where the intent of the ASME guidelines are considered based on the knowledge of the material properties [4, 5, 6, 7], listed in Table 4, and FEA analysis. Specifically the cavity design is analyzed with respect to the specification for 2bar pressure at room temperature and 5bar pressure at cryogenic temperature. To satisfy the pressure requirements, thicker material is chosen for the cavity and jacket irises and drift tube.

Table 4: Mechanical Properties of Niobium and SS316L at Room Temperature and Cryogenic Temperature.

Marerial	Min. Yield Stress	Max. Allowable Stress
Room Temperature		
Nb (AS)	51 MPa	34 MPa
Nb (600˚)	48 MPa	32 MPa
Nb (800˚)	38 MPa	25 MPa
SS316L	170 MPa	115 MPa
Cryogenic Temperature (4K/2K)		
Nb (800˚)	317 MPa	171 MPa
SS316L	431 MPa	287 MPa

The peak stresses of SSR1 FEA analysis with various pressure load and boundary conditions are listed in Table 5. Comparing the analyses to allowable stress required by code, it is noted that the stresses on the cavity at cryogenic temperature and those on the jacket at all temperatures are lower than the threshold values and so are acceptable. Considering the cavity in cryomodule at room temperature, the beam pipe is free with the tuner disengaged. The maximal stress on the niobium is 35 Mpa, which is 8% higher than the allowable stress of niobium after 600˚C degassing. Since there is a 1/3 safety factor in the code, even in this worst case, there is still 25% margin to minimal yield strength of niobium considering a 600˚C degassing. The design is acceptable and in line with other spoke resonators being developed. As a safeguard to detuning from operational stresses, a degassing temperature of 600˚C is recommended rather than 800˚C.

Table 5: Peak Stresses of SSR1 FEA Analysis.

Pressure	Niobium	SS316L
2 bar (free)	35 MPa	66 MPa
2 bar (fixed)	37 MPa	65 MPa
5 bar (free)	87 MPa	164 MPa
5 bar (fixed)	92 MPa	161 MPa

FABRICATION CONSIDERATIONS

RISP SSR1 is in fabrication phase at PAVAC. Two half cells with beam tubes, flanges and ring stiffeners, and the spoke bar with drift tube and plate stiffeners will be formed, machined and welded. The target frequency for the initial stack-up measurement is 324.851MHz, while it will be 324.578MHz after fabrication of the jacketed cavity with 150µm BCP in total. The measurement uncertainty is about 40kHz, due to volume perturbation at the RF contacts. This error can be corrected by tuning the beam pipe flange after fabrication.

The cavity frequency is adjusted by trimming both irises after stack up measurement, which is different from conventional spoke resonator. Cavity iris and beam tube will be machined from a solid piece of bulk niobium. ±2mm machining allowance from nominal dimension is left on both irises. The frequency sensitivity of iris trimming is 420kHz/mm, and the total adjustment range is ±1.7MHz. The influence to E_{peak}/E_{acc} is less than 3% within the tuning range. In addition, the cavity length can be well controlled with this procedure.

Both half cells are welded along cavity equator, and then the RF ports are added. The final weld is the joint of the spoke bar and the cavity body. To slide the spoke bar into the cavity, the elliptical axis of the bottom spoke base is 1mm less than that of the top. The transverse kick effect due to the asymmetric spoke geometry is 0.2µrad per cavity for β=0.3 proton beam, and even less for higher A/q ion beam and considered as negligible.

CONCLUSION

The RISP SSR1 is designed according to the specifications. The balloon variant is chosen to suppress multipacting around operational gradient. The low E_{peak}/E_{acc} promises 2.52MV accelerating voltage for beam with optimized geometry β at 35MV/m peak electric field. The mechanical design complies to ASME guidelines. Pressure sensitivity is minimized by optimizing jacket geometry and adding stiffeners to spoke. Special frequency adjustment procedure is applied due to the balloon geometry. RISP SSR1 is in fabrication phase, and will be processed and tested at TRIUMF. More details will be reported in the future.

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