DESIGN PROGRESS OF SSR1 SINGLE SPOKE RESONATOR FOR RAON

H. J. Cha[#], G. T. Park, H. C. Jung, H. J. Kim, D.-O Jeon, IBS/RISP, Daejeon, South Korea
Z. Y. Yao, V. Zvyagintsev, R. E. Laxdal, TRIUMF, Vancouver, BC, Canada

Abstract

The progress towards the design of a high efficient SSR1 superconducting cavity (β=0.3 and f=325 MHz) is reported. Especially, we propose a cavity structure with rounded end walls for improving mechanical properties and minimizing multipacting. Several issues related with fabricating the SSR1 cavity are added.

INTRODUCTION

An advanced heavy ion accelerator for basic sciences and multiple applications, called "RAON", is under construction in Daejeon, South Korea. The fabrication of prototypes for four different types of superconducting cavities, QWR, HWR, SSR1 and SSR2, is scheduled based on the on-going technical designs. The SSR1 cavity, which will be operating in the SCL2 of the RAON, is for reaccelerating the stable isotope heavy ion beams from HWR cavities in the SCL1 (β=0.12) to higher energy (β=0.3) at 325 MHz. We introduce the early-stage RF design of the SSR1 cavity having traditional flat end walls and its several mechanical performances. The variant of the SSR1 cavity by modifying the end wall structure has been considered for better RF and mechanical characteristics as well as multipacting suppression. The cavity imperfection due to the possible errors when fabricating the cavity and the transverse field asymmetry at the spoke is also discussed.

INITIAL DESIGN OF SSR1 CAVITY

In order to design a high efficient superconducting cavity, RF parameters related with the cavity performance should be optimized. For example, for particle beams passing through a cavity to get maximum energy gain, the acceleration gradient should be maximized by decreasing the peak electromagnetic (EM) fields. We have performed EM simulations with changing the design parameters of a SSR1 superconducting cavity using CST MWS code. Figure 1 shows the structure and EM field distribution of the SSR1 cavity having traditional flat end walls. Its RF characteristics are listed in Table 1.

Mechanical analyses of the SSR1 cavity were performed using CST MPhysics code. First, simulations on structural deformation under atmospheric pressure were done. It was assumed that the pressure was uniformly distributed at inside and outside of the cavity and both beam pipes were rigidly fixed. The deformation at end walls near the beam pipes is expected to be the maximum displacement of 686 μm and the 1st principal
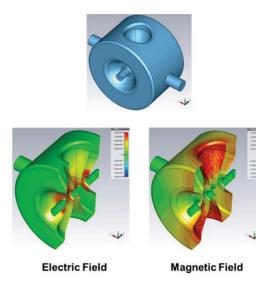

Figure 1: SSR1 cavity having flat end walls and its field distribution.

Table 1: RF Characteristics of SSR1 Cavity Having Flat End Walls

RF parameter	Value
Q (x 10^9)	9.2
QR_S (Ω)	97.6
R_{sh}/Q (Ω)	247
V_{acc} (MV)	2.3
E_{acc} (MV/m)	8.3
E_{peak} (MV/m)	35
B_{peak} (mT)	52
E_{peak}/E_{acc}	4.2
B_{peak}/E_{acc} (mT/MV/m)	6.2
Stored energy (J)	10.6
Dissipated power (W)	2.4

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#hjcha@ibs.re.kr

(or Von Mises) stress of 351 MPa. With the resonant frequency calculated from EM analysis for the deformed cavity, the frequency shift per unit pressure df/dP for the bare cavity is estimated to be approximately 135 Hz/Torr.

Second, if the beam ports of the SSR1 cavity are forced using a mechanical tuner, the resonant frequency shift must be caused by elastic deformation of the cavity. When the same pressure is applied to both beam ports of the cavity in opposite directions, one can estimate the maximum displacement deformed in the beam propagation direction. Thus, the stiffness k could be calculated to be 0.91 kN/mm. With changing the displacements at both beam ports, the frequency shifts were also calculated from EM analyses. The estimated sensitivity s is –879 kHz/mm.

Third, in case of pulse operation for a superconducting cavity, the Lorentz force detuning (LFD) is generated by EM fields formed by RF in the cavity wall. The cavity is deformed by the Lorentz pressure, which results in the resonant frequency shift proportional to the square of the acceleration gradient. According to mechanical analyses, the maximum displacement is 260 nm and the 1st principal stress is 168.8 kPa. With the calculated frequency shift of -262 Hz and the acceleration gradient of 8.3 MV/m, the LFD coefficient K_L is expected to be approximately –3.8 Hz/(MV/m)^2. Table 2 shows the summary of the mechanical properties mentioned above.

Table 2: Mechanical Characteristics of the Bare SSR1 Cavity Having Flat End Walls

Mechanical parameter	Value
df/dP (Hz/Torr)	135
Stiffness, k (kN/mm)	0.9
Sensitivity, s (kHz/mm)	-879
LFD coeff., K_L (Hz/(MV/m)^2)	-3.8

SSR1 CAVITY HAVING ROUNDED END WALLS

The resonant frequency shift due to the fluctuation of liquid helium pressure is critical issue to resolve for stable operation of a superconducting cavity in a cryomodule. In case of a traditional single spoke cavity having flat end walls, the frequency shift is severe such that in our case, the df/dP for the bare SSR1 cavity is ~135 Hz/Torr as shown in Table 2. Even though the utilization of stiffeners and rigid connection of the cavity with a helium jacket can reduce the frequency sensitivity, partial cavity modification is required for simplicity with minimal

stiffeners and cost effectiveness. For this purpose, several research groups proposed the spoke cavity variants [1-3]. We consider the SSR1 cavity having rounded end walls as shown in Fig. 2. The ease of fabrication was also considered. EM simulations for the modified SSR1 cavity were performed and the optimized RF parameters are listed in Table 3. Even though R_{sh}/Q is a little bit lower than that of the cavity having flat end walls and B_{peak} increases a little bit, both V_{acc} and E_{acc} increased with reducing E_{peak}/E_{acc} and B_{peak}/E_{acc}. Coupled analyses will be followed for mechanical and EM characterization of the modified cavity. In addition, it is expected that the SSR1 cavity having rounded end walls can minimize the
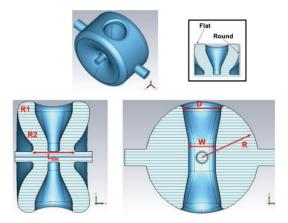

Figure 2: SSR1 cavity having rounded end walls.

Table 3: RF Characteristics of the SSR1 Cavity Having Rounded End Walls

RF parameter	Value
Q (x 10^9)	8.9
QR$_S$ (Ω)	94.2
R$_{sh}$/Q (Ω)	230
V$_{acc}$ (MV)	2.6
E$_{acc}$ (MV/m)	9.2
E$_{peak}$ (MV/m)	35
B$_{peak}$ (mT)	60
E$_{peak}$/E$_{acc}$	3.8
B$_{peak}$/E$_{acc}$ (mT/MV/m)	6.5
Stored energy (J)	13.9
Dissipated power (W)	3.2

higher-order multipacting due to the smoothness of the cavity inner shape. Multipacting simulations for both cavities with flat and rounded end walls are in progress using CST PS code.

FABRICATION ERROR AND MISALIGNMENT

For example, suppose that the iris-to-iris distance in the SSR1 cavity is changed by ±2.5 mm as a fabrication error, the electric field in the longitudinal direction E_z will decrease (+) or increase (-) by small amount of 1%. However, severe resonant frequency shifts are predicted as shown in Fig. 3. The effects due to misalignment like angle variation of the cavity components when assembling them are also being studied.
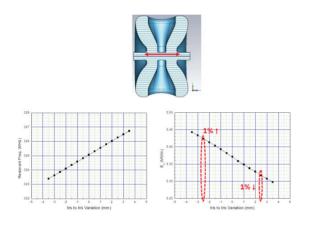

Figure 3: Variations of resonant frequency and longitudinal electric field with respect to iris-to-iris distance in the SSR1 cavity.

TRANSVERSE FIELD ASYMMETRY

The field asymmetry in transverse direction due to the absence of axial symmetry in HWR and SSR structures can result in the distortion of particle beams. One of the solutions for compensation for the asymmetry is the use of an elliptical beam tunnel instead of a circular one at the center conductor [4]. The beam tunnel radius at the spoke of the SSR1 cavity was designed to be 25 mm. Elliptical beam tunnels with combination of long and short axes ranged from 22 mm to 28 mm were used for EM simulations. Figure 4 shows the results predicted at positions of 10 mm in horizontal and vertical directions, respectively. The difference between transverse electric fields is approximately 200 kV/m. More studies for enhancing the beam focusing at the spoke are planned.
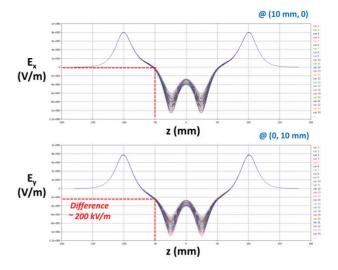

Figure 4: Variations of transverse electric fields along longitudinal axis with different elliptical beam tunnels at the spoke.

CONCLUSION

EM and mechanical analyses for the traditional SSR1 cavity having flat end walls were completed. The upgraded SSR1 cavity having rounded end walls is expected to exhibit the enhanced performances such as insensitiveness to liquid helium pressure fluctuation and multipacting suppression. The analyses on fabrication error and misalignment and transverse field asymmetry of the modified cavity are in progress. All possible case-studies should be done for realizing the RAON.

ACKNOWLEDGMENT

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