UPDATE ON SSR2 CAVITIES DESIGN FOR PROJECT X AND RISP*

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Abstract

Single Spoke Resonators SSR2 (f = 325 MHz) are under development at Fermilab. These superconducting RF cavities can meet requirements of Project X (FNAL) and RISP (Korea). The initial design of SSR2 cavities has been modified and optimized in order to satisfy the necessities of both projects. This paper will discuss the RF optimization of a single spoke resonator with a 50 mm beam pipe aperture and an optimal β of 0.51. The mechanical design of the cavity and the Helium Vessel will also be presented. This is aimed to guarantee a low He pressure sensitivity *df*/dp of the entire system.

INTRODUCTION

Project X is based on a 3 GeV CW superconducting linac being developed at Fermilab to support the intensity frontier research in elementary particle physics [1]. Figure 1 shows the arrangement of the linac and the type of resonators that are needed. The low energy section of the linac (2.1-177 MeV) consists of three types of resonator: 162.5 MHz half wave resonator (HWR) with β=0.11 (2.1-11 MeV), 325 MHz single spoke resonators SSR1 of β=0.22 (11-38 MeV) and 325 MHz single spoke resonators SSR2 having β 0.51, (38-177 MeV). The high energy section of the linac from 0.177 to 3 GeV comprises two families of cavity with β=0.6 and β=0.9. The SSR2 section of Project X linac consists of seven cryomodules. Each cryomodule contains 5 SSR2 resonators and 3 solenoids in the arrangement s-c-c-s-c-c-s-c. The design of SSR2 proposed in [2] has been modified to satisfy requirements of both Project X (FNAL) and RISP (Korea). This paper presents the RF optimization of a 50 mm beam pipe aperture resonator and the conceptual design of the dressed cavity aimed to achieve a near zero frequency dependence on pressure (*df/dp*). The main components of a SSR2 cavity will be referred to as: shell, spoke and endwall (two per cavity).

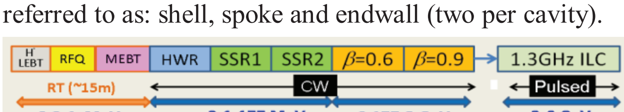

Figure 1: SRF map of the linac for Project X.

RF DESIGN

SSR2 design has been changed during the last year: the previous design [3] was based on Fermilab Project X needs; the latest design is intended to be used in both FNAL Project X and RISP. In order to meet RISP requirements, the optimal beta of SSR2 cavity was changed from 0.47 to 0.51 and the beam pipe aperture was increased from 40 to 50 mm. The choice of optimal beta was based upon estimations that took into account the requirements of both Project X and RISP linacs. The Korean linac will accelerate heavy ions up to 200 MeV/u using SSR2 cavities, while in Project X SSR2 will be used up to about 156 MeV for an H- beam. The range of β_{opt} that minimizes the number of SSR2 cavities in Project X goes from 0.46 to 0.55[2] and is presented in Figure 2. Changing β_{opt} from 0.47 to 0.51 does not affect the accelerating efficiency for Project X, and at the same time it overlaps with the optimal range required by the RISP linac.

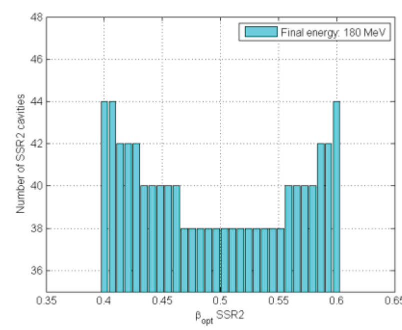

Figure 2: N. of SSR2 cavities vs β_{opt} for Project X [2].

The normalized Transit Time Factors (TTF) of an SSR2 cavity having β_{opt} = 0.47 and β_{opt} = 0.51 are shown in Figure 3. Despite the decrease in TTF at the beginning of the particle beta range, the design with β_{opt} = 0.51 is capable of sustaining a higher energy gain per cavity. This is the reason why the required total number of SSR2 cavities does not increase.

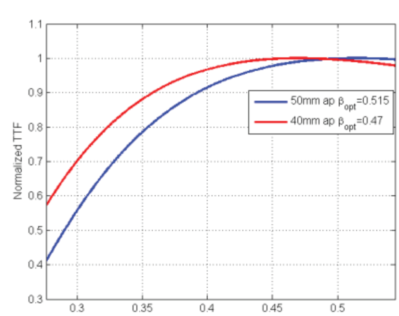

Figure 3: SSR2 normalized TTF comparison.

Since fundamental parameters of the spoke resonator such as optimal beta and aperture have changed, the cavity geometry was re-optimized and deeply modified: the gap length, the inner electrode and the cavity endwalls were changed in order to achieve the best electromagnetic performance. The endwall profile was optimized in order

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to minimize the electric surface peak field and to enhance mechanical stability. The spoke base has an elliptical section, which helps in having a more uniform magnetic field and, hence, a lower magnetic surface peak field. The dependence of B_{peak}/E_{acc} on the ratio R/r between the two radiuses of the spoke base is shown in Figure 4.

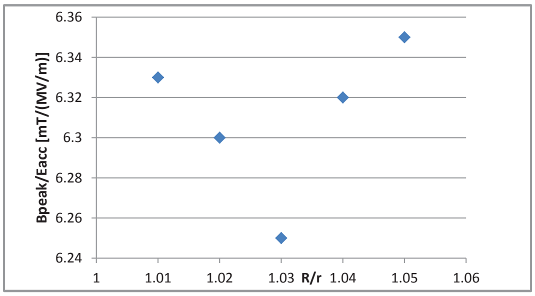

Figure 4: B_{peak}/E_{acc} vs R/r.

The gap and spoke thickness were chosen to match the β_{opt} requirement. The transverse dimension of the central part of the spoke has been tweaked to lower the peak electric field. This modification was necessary because of the new endwall profile, which ensures better mechanical stability of the resonator. Figure 5, shows the dependence of E_{peak}/E_{acc} as a function of the inner electrode transverse dimension.

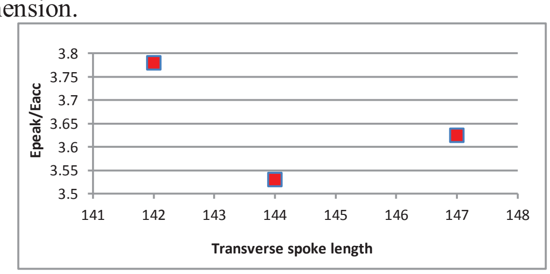

Figure 5: Epeak/Eacc vs spole transverse length.

RISP project requires an increase of the beam pipe aperture from 40 to 50 mm. The R/Q factor of the spoke resonator is only slightly affected by this modification, but it does not appear to be a limiting factor. Figure 6 shows the electric and magnetic fields distribution in SSR2 RF volume. The fields were calculated with Comsol eigen-frequency solver.

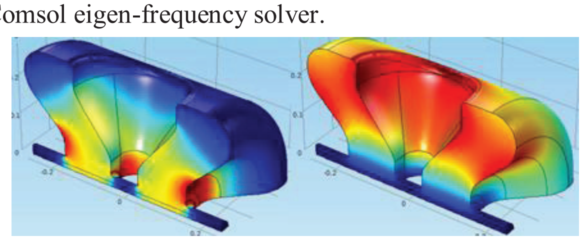

Figure 6: SSR2 electric (left) and magnetic (right) field.

Project X requires the peak magnetic field not to exceed 70 mT and a peak electric field not higher than 40 MV/m during operation. In this case, the peak magnetic field constraint becomes the limiting factor for SSR2. Given the maximum of 70 mT, each cavity will provide a maximum energy gain of more than 5 MeV.

Table 1 summarizes all the electro-magnetic parameters of the new cavity design; the effective length is defined as $L_{eff} = \beta_{opt}\lambda$. This is commonly used at Fermilab for single spoke resonators and is consistent with the definition given in [3].

Table 1: Electro-magnetic Parameters of SSR2

Parameter	Value
Frequency [MHz]	325
Aperture [mm]	50
β_{opt}	0.514
Diameter [mm]	560.8
Length [mm]	537.2
$L_{eff} = \beta_{opt}\lambda$ [mm]	475.3
R/Q, Ω	275.9
G, Ω	118.6
E_{peak}/E_{acc}	3.53
B_{peak}/E_{acc} [mT/MV/m]	6.25
Max energy gain [MeV]	5.32
Max E_{acc} [MV/m]	11.2

MECHANICAL DESIGN

This section shows the mechanical design of the jacketed SSR2 resonator at a conceptual level. It presents how a near zero He pressure sensitivity *df/dp* can be achieved. Results from finite element analyses will also be presented.

Cavity Design

Figure 7 shows a CAD model of the SSR2 cavity. This will be made of 2.8 mm thick high RRR Niobium sheet and by a 4 mm thick collar that connects the spoke to the circular shell. The structural integrity of the cavity during the leak check test and liquid helium is ensured by the presence of 6 beam pipe ribs and a stiffening ring on each of the two endwalls. These stiffening elements are made of reactor grade Nb and have been optimized for the following working conditions:

- 0.1 MPa external pressure and free cavity (leak check).
- 0.2 MPa external pressure and beam pipes fixed (VTS)

Figure 7: One quarter CAD model of the SSR2 resonator.

Figure 8 shows the Von Mises Equivalent stress in the resonator during the leak check conditions. The maximum stress that develops in the material is acceptable and the cavity will not collapse under the pressure differential during the tests. The buckling load of the bare cavity is 0.8 MPa, which indicates that no circumferential

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stiffening ribs are required to stiffen the shell; the deformed shape is presented in Figure 9.

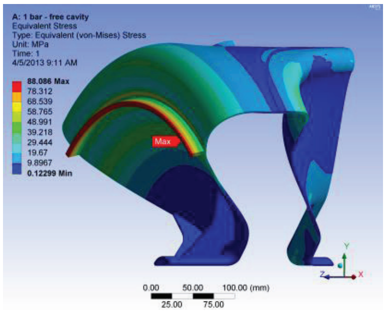

Figure 8: Von Mises Stress distribution for 0.1 MPa pressure and free cavity.

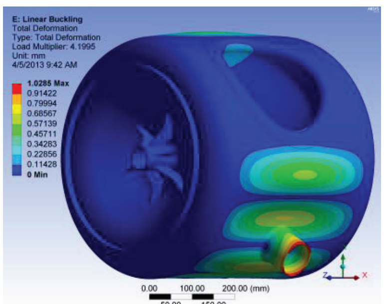

Figure 9: Buckled mode shape of the SSR2 resonator.

The stiffness of the endwall for an axial load applied to the beam pipe is 19 kN. The sensitivity of the endwall to axial deformation is – 228.7 kHz/mm. These result in a predicted force at the beam pipe of 12 kN to achieve a 135 kHz coarse tuning range.

Helium Vessel

The SSR2 resonator will be jacketed with a 6mm stainless steel 316L Helium Vessel and the same layout of the dressed SSR1 G3 will be adopted. The vessel will be connected to the Nb cavity through the coupler ports, the beam pipes and a transition ring. The power coupler will be an adjusted version of the one that has been already developed for SSR1 [4]. A bellows is introduced as a passive tuning device aimed to reduce the system sensitivity to He bath pressure fluctuations and its diameter has been optimised for *df/dp* near zero Hz/mbar. The rendering of the jacketed SSR2 resonator is presented in Figure 10 wherein one can identify all the features that have just been described.

Figure 10: Rendering of the jacketed SSR2 resonator.

The Helium Vessel has been designed and optimized following the approach proposed in [5]. The predicted *df/dp* of the jacketed SSR2 cavity is -2.2 Hz/mbar and it has been evaluated with COMSOL by a coupled mechanical-RF simulation. Finally, Figure 11 shows the deformed shape of the jacketed SSR2 resonator under a He pressure of 1 atm, this result has been used in the coupled RF-Mechanical simulation and produced a *df/dp* of -2.2 Hz/mbar.

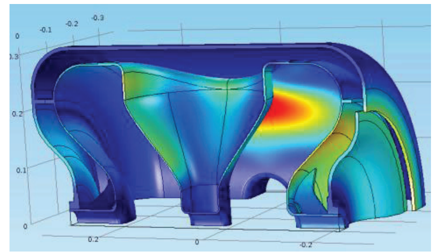

Figure 11: Deformed shape of jacketed SSR2 under a He pressure of 1 atm. This gives a df/dp of -2.2 Hz/mbar.

CONCLUSIONS

The RF design of a SSR2 resonator that meets the requirements of both Project X (FNAL) and RISP (Korea) has been presented. The mechanical design of the bare cavity was aimed to ensure structural integrity of the system under well defined loading conditions. A Stainless Steel Helium Vessel has also been optimized in such a way as to ensure a He pressure fluctuation sensitivity *df/dp* as close as possible to zero.

Future pressure rating analyses will be performed to guarantee a maximum allowable working pressure (MAWP) of 0.2 MPa at room temperature and 0.4 MPa at 4K according to the ASME pressure vessel code.

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