UPDATE ON SSR2 CAVITIES DESIGN FOR PROJECT X AND RISP*

M. Merio#, P. Berrutti#, M.H. Awida, I. Gonin, T.N. Khabiboulline, D. Passarelli, Y.M. Pischalnikov, L. Ristori, N. Solyak, V.P. Yakovlev, FNAL, Fermilab, Batavia, IL 60510, USA

Abstract

Single Spoke Resonators SSR2 (f = 325 MHz) are under development at Fermilab. These 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. The paper will discuss the RF optimization for a single spoke resonator with a 50 mm beam pipe aperture and an optimal β of 0.51. Further, the approach to the mechanical design of the cavity will be presented together with the proposed Helium Vessel intended to guarantee a low He pressure sensitivity *df*/dp of the entire jacketed SSR2 and actively control the microphonics.

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 resonator that are needed. The low energy section of the linac (2.1-177 MeV) consists of three types of resonator: 162.5 MHz 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 cavities with β 0.6 and β 0.9. Seven SSR2 cryomodules made of 5 resonators and 3 solenoids in the arrangement s-c-c-s-c-c-s-c are needed for the Project X linac. The design of SSR2 that was 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 *df/dp*.

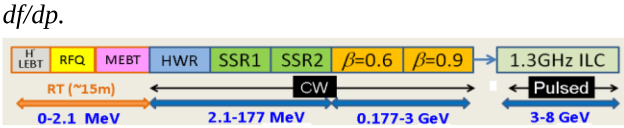

Figure 1: SRF map of the linac for Project X

RF DESIGN

SSR2 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. To meet RISP requirements the optimal beta of SSR2 cavity has changed going from 0.47 to 0.51 and the beam pipe aperture has been increased to 50 mm. The choice of optimal beta has been based upon careful estimations that took into account both the linear accelerators Project X and RISP. 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 180 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], see Figure **2**, so the change of β_{opt} does not affect the accelerating efficiency for FNAL project, while it overlaps with the optimal range for RISP linac.

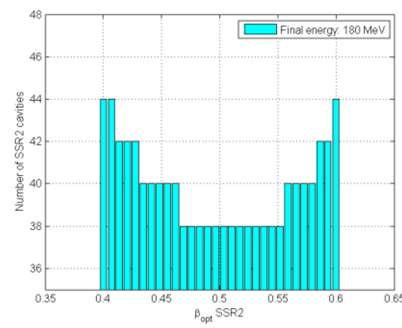

Figure 2: N. of SSR2 cavities vs $\boldsymbol{\beta_{opt}}$ for Project X [2]

In Figure **3** below the normalized transit time factors of SSR2 cavity having $\beta_{opt} = 0.47$ and $\beta_{opt} = 0.51$ are shown. Despite the loss in TTF at the beginning of the particle beta range, the new cavity design with higher β_{opt}, is capable of a higher energy gain per cavity. This is the reason why the total number of SSR2 cavities needed does not increase.

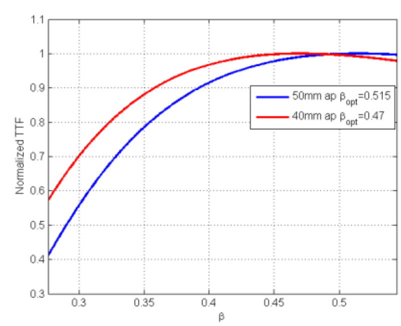

Figure 3: SSR2 normalized TTF comparison

Since fundamental parameters of the spoke resonator have changed, such as optimal beta and aperture, the cavity geometry has been re-optimized and deeply modified: the gap length, the inner electrode and the cavity walls have been changed in order to achieve the best electromagnetic performances. The wall profile has been optimized in order to minimize electric surface peak field and to enhance mechanical stability. The spoke base has an elliptical section, which helps in having a more

*Work supported by DOE

merio@fnal.gov, berrutti@fnal.gov

uniform magnetic field and, hence, a lower magnetic surface peak field. The dependence of B_{peak}/E_{acc} from the ratio R/r between the two radiuses of the spoke base is shown in Figure 4.

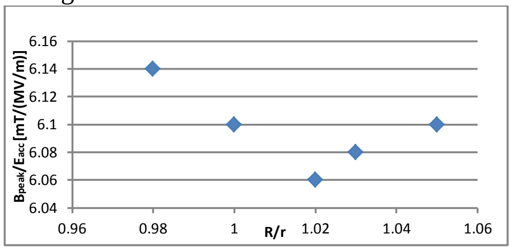

Figure 4 B_{peak}/E_{acc} vs R/t

The gap and spoke thickness have been chosen in such a way as to match the β_{opt} requirement. Moreover, during the last step of the optimization process, since the wall profile has been defined from mechanical constraints as well, the transverse dimension of the central part of the spoke has been adjusted to lower the peak electric field. The graphic below, Figure 5, shows the dependence of E_{peak}/E_{acc} as a function of the inner electrode transverse dimension.

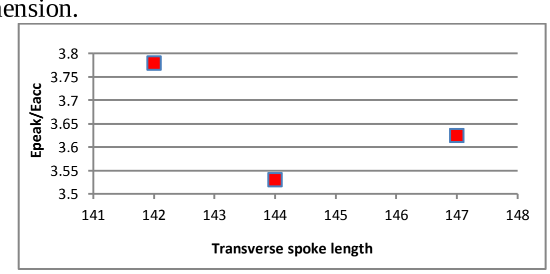

Figure 5: Epeak/Eacc vs spole transverse length

The beam pipe aperture is now increased to 50 mm to comply with the request by RISP, this modification slightly affects the R/Q factor of the spoke resonator but it does not appear to be limiting. Figure 6 shows electric and magnetic field distribution in SSR2 RF volume, fields have been calculated with Comsol eigen-frequency solver.

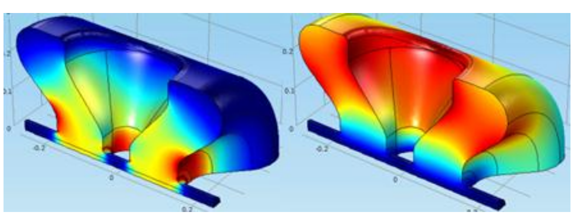

Figure 6: SSR2 electric (left) and magnetic (right) field

SSR2 cavity will provide a maximum energy gain per cavity higher than 5 MeV, given the surface field limitation of Project X. The surface magnetic field is the limiting factor of this cavity: Project X requires the peak magnetic field not to exceed 70 mT and the electric not higher than 40 MV/m during operation.

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

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}	5.66
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 approach to the mechanical design of the jacketed SSR2 resonator at a conceptual level and presents how 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 collar that connects the spoke to the circular shell. The structural integrity of the cavity during the leak check test and the VTS 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)

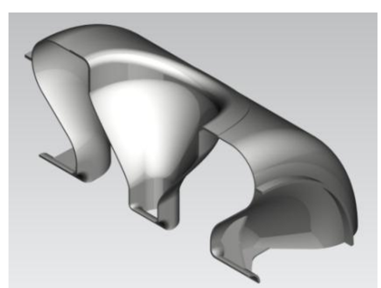

Figure 7: One quarter CAD model of the SSR2 resonator

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 meaning that no circumferential stiffening ribs are required to stiffen the shell; the deformed shape is presented in Figure 9.

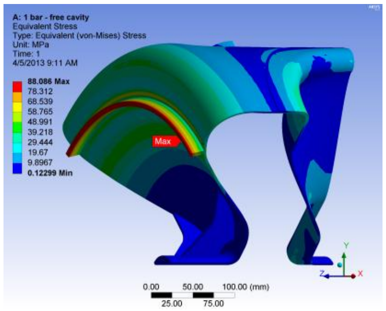

Figure 8: Von Mises Stress distribution for 0.1 MPa pressure and free cavity

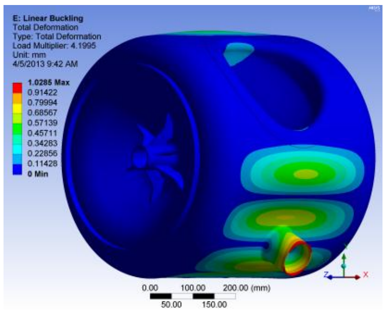

Figure 9: Buckled mode shape of the SSR2 resonator

The predicted beam pipe stiffness is 19.5 kN/mm and the sensitivity of the resonator is -228.7 kHz/mm. Thus the force required to achieve a 135 kHz coarse tuning range is 12 kN.

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 adjustment of the one that has been already developed for SSR1[4]. A bellow 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* the closest possible to 0 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.

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 10: Rendering of the jacketed SSR2 resonator

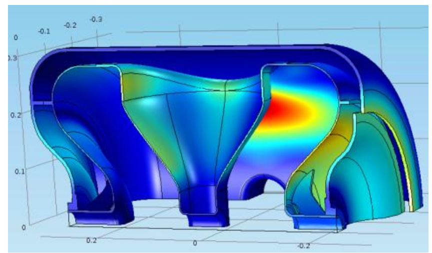

Figure 11: Deformed shape of jacketed SSR2 under a He pressure of 1 atm. This gives a df/dp of -2.2 Hz/mbar

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 to ensure a He pressure fluctuation sensitivity *df/dp* the closest 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 4 K will be performed according to the ASME pressure vessel code Section VIII Division 2 ‘Design by analysis’.

REFERENCES

[1] S. Nagaitsev, “Project X - A New Multi-Megawatt Proton Source at Fermilab”, invited talk, PAC’11, New York, 2011, FROBN3

[2] P. Berrutti et al., “Optimization of the Geometric Beta for the SSR2 Cavities of the Project X”, IPAC’12, New Orleans, Louisiana, 2012, WEPPC045

[3] I. Gonin et al., “EM Design of the Low-Beta SC cavities for the Project X front end”, PAC’11, New York, NY, 2011, TUP070

[4] S. Kazakov et al., “Main Couplers for Projext X”, IPAC’12, New Orleans, Louisiana, 2012, WEPPC050

[5] D. Passarelli et al., “Pressure Sensitivity Characterization of superconducting spoke cavities”, IPAC’12, New Orleans, Louisiana, 2012, WEPPC056