DESIGN OF 325 MHZ SINGLE SPOKE RESONATOR AT FNAL *

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Abstract

The proposed 8-GeV driver at FNAL [1] is based on about 400 independently phased SuperConducting (SC) resonators. In this paper the design of 325 MHz (β=0.22) Single Spoke Resonator (SSR) for the Proton Driver front end is presented. We describe the optimization of the SSR geometry, the goal being the minimization of the E_{peak}/E_{acc} and B_{peak}/E_{acc} ratios. The aforementioned optimization has been achievedusing the software package Microwave Studio (MWS) and has led to very encouraging results. We also report on the coupled ANSYS-MWS analysis on the SSR mechanical properties. Finally the preliminary power coupler RF design for the SSR is presented.

INTRODUCTION

SC cavities operating at 1300 MHz and originally developed for the electron-positron linear collider (ILC) can be directly applied for acceleration of H^- or proton beams above approximately 1.2 GeV. Squeezed ILC-style cavities designed for β_G=0.81 can be used in the energy range from approximately 400 MeV to 1.2 GeV. The front end of the 8-GeV linac is defined as a section operating at 4th sub-harmonic of the ILC frequency [2].

The proposed front end uses both room temperature (RT) and SC short cavities alternating with focusing elements. The RT section includes ion source, RFQ, MEBT and 15 five-cell RT cross-bar H-type cavities [5]. The SC section consists of single, double and triple-spoke resonators accelerating an H^- ion beam up to 410 MeV. Multi-spoke SC cavities have been developed and demonstrated excellent performance at 345-352 MHz [3,4] and can be easily modified to 325 MHz.

The total length of the front end is 115 m. Advantages of single-frequency medium energy proton linac based on multi-spoke cavities have been discussed elsewhere [6]. In this paper the design of 325 MHz Single Spoke Resonator (SSR, β=0.22, energy range 10-33 MeV) for the Proton Driver front end is presented.

SINGLE SPOKE RESONATOR OPTIMIZATION

The optimization of the SSR has been done by using of MWS software. In Figure 1 the main geometrical parameters used for optimization are shown.

Beam dynamics considerations led us to the choice of β=0.22 and a 30 mm aperture diameter. Also an iris-to-iris distance L_{iris} = 2/3 βλ has been chosen.

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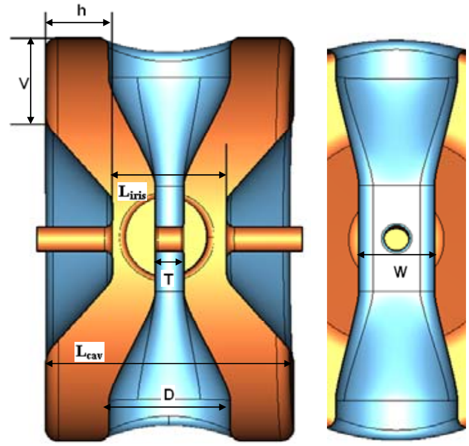


Figure 1. Cross section of the SSR with the main parameters used in the optimization process: L_{cav} – cavity length, L_{iris} – iris to iris length, D – spoke diameter, W – spoke width, T – spoke thickness, h and v – end cup dimensions.

The spoke width W and gap ratio T/L_{iris} were optimized to achieve a low peak electric field. The results of the simulations are shown in Figure 2.

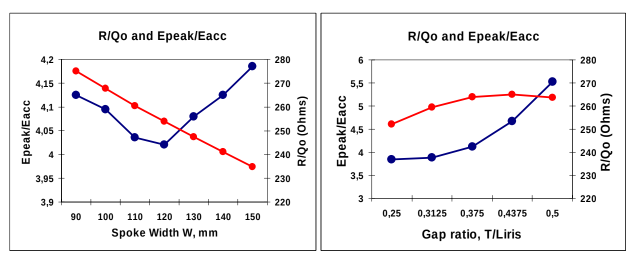
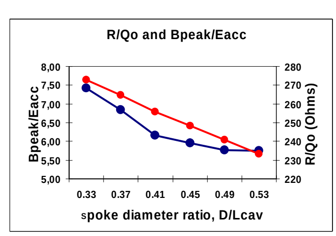


Figure 2. R/Q_0 (red) and E_{PEAK}/E_{ACC} (blue) vs. W and T/L_{iris}

The ratio D/L_{cav} and the end cup profile dimensions were optimized to achieve a low peak magnetic field. The results of the simulations are shown in Figure 3.



	Bpeak/Eacc			
V \ h	50	60	70	80
30	8,63	7,70	7,13	6,54
55	8,39	7,61	6,98	6,40
80	8,13	7,36	6,75	6,21
105	7,95	7,19	6,55	5,96

Figure 3. Dependence of R/Q_0 (red) and B_{PEAK}/E_{ACC} (blue) on the spoke and the end cup profile dimensions (in mm).

The table below shows the RF parameters of the optimized SSR. The effective length used to define E_{acc} is equal to βλ.

E_{PEAK}/E_{ACC}	3.86
B_{PEAK}/E_{ACC} (mT/MV/m)	6.25
G(Ω)	87
R/Q_0(Ω)	262
β_{opt}	0.224

SSR MECHANICAL DESIGN AND STRESS ANALYSIS

The SSR mechanical structure needs to withstand the pressure exerted by the liquid helium providing at the same time enough stiffness to prevent the Lorentz forces from causing an appreciable frequency shift (Lorentz detuning).

In Figure 4 a cross section of the complete SSR structure is shown.

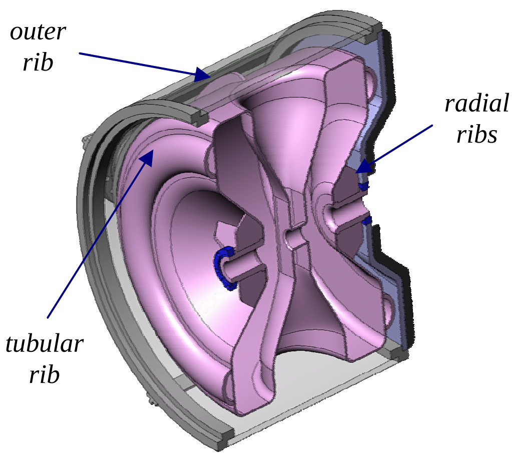


Figure 4. Cross section of the SSR structure. The helium vessel is also shown in gray. The stiffening ribs systems are highlighted.

Each end wall of the spoke resonator is reinforced by two systems of ribs: a tubular rib with elliptical section in the end wall outer region and six radial daisy-like ribs in the inner region (*nose*). These two systems are not connected to facilitate a controlled displacement of the nose area for cavity slow tuning. A third and final system of 4 ribs is present on the cylindrical portion of the cavity. All ribs are made of reactor grade niobium.

The cavity beam pipe is copper brazed to a conflat® compatible flange (in blue in Figure 4), welded directly to the helium vessel end wall in order to provide the necessary SSR support.

In Figure 5 it is possible to see the analyzed assembly meshed. Due to the symmetry, only 1/8 of the structure was modeled. We applied a boundary condition of full constraint at the helium vessel power coupler port. The loading conditions were a thermal differential ΔT=-296K and an internal pressure variation from atmospheric to 2.3×10^5 Pa (2.25atm).

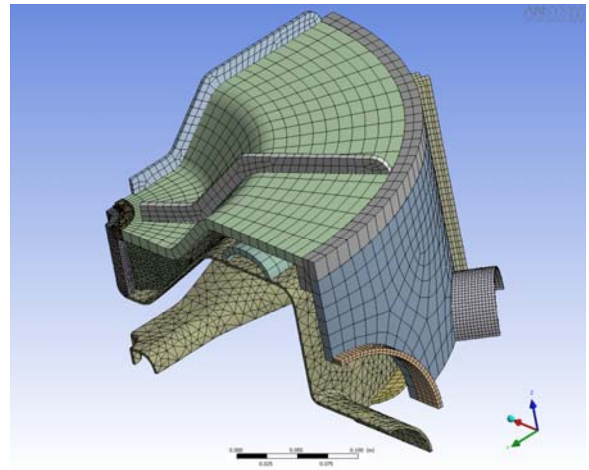


Figure 5. Finite element model of an SSR with helium vessel. Due to the symmetry, only 1/8 of the structure has been modeled.

Table 1 summarizes the loading cases we studied, while Figure 6 and Figure 7 show contour plots of the total deformation and the von Mises stress respectively.

From Table 1 it can be seen that for internal pressures higher than 1.25 atm the yield strength of the high RRR niobium (≈ 48 MPa at room temperature) was reached in highly localized points. Although no material plasticity was included in the model, it is reasonable to assume that such mechanism would lead to some beneficial stress relief. The implementation of material plasticity is the subject of further investigations.

Loading Condition	**Von Mises** [MPa]	**Tot Def** [micron]
1atm + ΔT= -296K	35.2	87
1.25atm +ΔT= -296K	43.4	109
1.5atm +ΔT= -296K	52.4	131
1.75atm +ΔT= -296K	61.4	153
2atm +ΔT= -296K	69.6	175
2.25atm +ΔT= -296K	78.6	196
ΔT=-296K only	0.05	0.40

Table 1: For each loading condition, von Mises stress and total deformation limited to the SSR body are reported.

POWER COUPLER DESIGN

The RF design of the main power coupler was performed by using the Ansoft HFSS software. Two types of couplers were considered: antenna coupler with electric coupling and loop coupler with magnetic coupling.

The optimum position of the antenna coupler is located in the plane perpendicular to the spoke, where the minimum of the surface magnetic field and a strong electric field are located. Loop coupler needs magnetic field for coupling with the cavity and should be located closer to spoke base where the magnetic field is maximum, as shown in Figure 8.

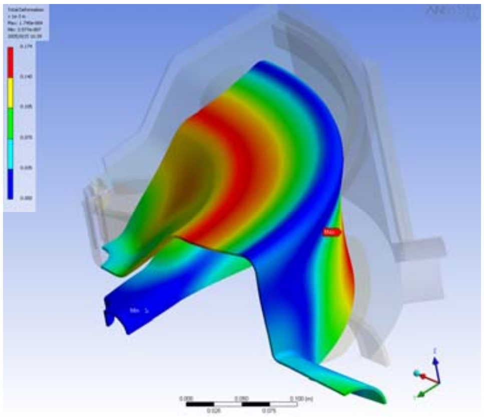


Figure 6. Total deformation in [m] of a single spoke resonator. For clarity only the SSR body is shown.

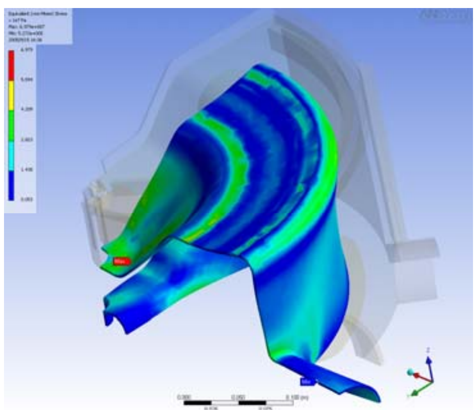


Figure 7. Von Mises stress in [Pa] on a single spoke resonator. For clarity only the SSR body is shown.

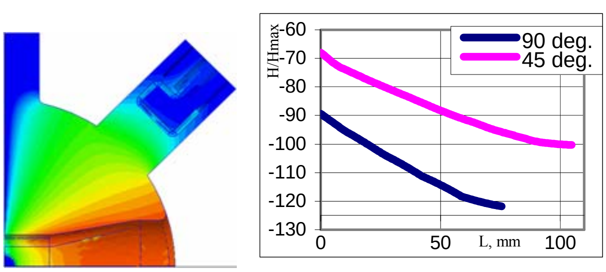


Figure 8. Left: magnetic field amplitude in mid plane of the cavity and spoke surface. Right: magnetic field attenuation in the coupler tube for two different angular positions of the coupler port.

In the case of coupler positioned at 45^0 respect to the spoke, there is a dipole component of the magnetic field in the port tube. To eliminate power dissipation on normal conductive flanges, the port tube length should be longer in this situation. Additionally, there is power dissipation on the antenna coupler tip. An antenna coupler perpendicular to the spoke works fine: we get small power dissipation on the surface of inner conductor and need only a short port tube, as shown in Figure 9.

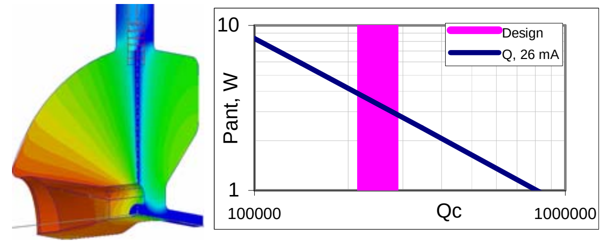


Figure 9. Left: magnetic field amplitude in 1/8 of the cavity with an antenna coupler. Right: pulse power dissipation on the coupler tip vs. external Q of the coupler.

A power coupler analysis shows a preference for the antenna coupler compared to the loop coupler [5].

CONCLUSION

We optimized the design of the SSR Superconducting cavities intended for the proposed 8-GeV LINAC driver at FNAL and operating at β=0.22 and 325 MHz. The optimization of the design provided values of E_{peak}/E_{acc} and B_{peak}/E_{acc} (3.86 and 6.25 mT/MV/m respectively) which should allow an improvement over many existing SSR SC cavities built in the past. The electromagnetic optimization was coupled to mechanical studies where the adoption of stiffening elements improved the operating conditions of the cavity. A study of the detuning Lorentz mechanism was not part of this work. Finally, a simulation of the power coupler design demonstrated the advantage of using an antenna coupler located at 90^0 respect to the spoke direction. The construction of a SSR SC cavity prototype will follow.

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REFERENCES

[1] G. W. Foster and J. A. MacLachlan, Proc. of the LINAC’02, Gyeongju, Korea, August 2002, p. 826.
[2] P.N. Ostroumov et al., Proc. of the PAC-2005, Knoxville, Tennessee, USA, 16-20 May 2005.
[3] K.W. Shepard et al., Proc. of the PAC-2003, Portland, Oregon, May 2003, p. 1297.
[4] J.R. Delayen, Proc. of the LINAC-2004, Lubeck, August 2004, p. 589
[5] Z. Li, R. Tiede, U. Ratzinger et al., Proc. of the LINAC’04, Lubeck, August 2004, p. 81.
[6] K.W. Shepard, P.N. Ostroumov, and J.R. Delayen, Phys. Rev. ST Accel. Beams 6, 080101 (2003).
[7] D. Arnold, T. Khabiboulline et al., Power couplers design at FNAL, to be published SRF2005