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# EXPLORATION OF MULTI-FOLD SYMMETRY ELEMENT-LOADED SUPERCONDUCTING RADIO FREQUENCY STRUCTURE FOR RELIABLE ACCELERATION OF LOW- & MEDIUM-BETA ION SPECIES

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*Abstract*

Reliable acceleration of low- to medium-beta proton or heavy ion species is needed for future high current superconducting radio frequency (SRF) accelerators. Due to the high-*Q* nature of an SRF resonator, it is sensitive to many factors such as electron loading (from either the accelerated beam or from parasitic field emitted electrons), mechanical vibration, and liquid helium bath pressure fluctuation etc. To increase the stability against those factors, a mechanically strong and stable RF structure is desirable. Guided by this consideration, multi-fold symmetry element-loaded SRF structures (MFSEL), cylindrical tanks with multiple (n>=3) rod-shaped radial elements, are being explored. The top goal of its optimization is to improve mechanical stability. A natural consequence of this structure is a lowered ratio of the peak surface electromagnetic field to the acceleration gradient as compared to the traditional spoke cavity. A disadvantage of this new structure is an increased size for a fixed resonant frequency and optimal beta. This paper describes the optimization of the electro-magnetic (EM) design and preliminary mechanical analysis for such structures.

## INTRODUCTION

SRF acceleration has become an enabling technology and many SRF accelerators are under construction or proposed world-wide for research in fundamental sciences and applications of society importance. TEM-type cavity structures, such as Quarter Wave Resonator (QWR), Half Wave Resonator (HWR) and spoke cavities [1] are usually chosen for accelerating protons or heavy ion species at low and medium beta (beta=v/c). Future heavy ion colliders such as MEIC [2], HIAF [3] are examples of proposed heavy ion machines that require SRF acceleration. A particular accelerating structure has its advantages and disadvantages over others in terms of mechanical (such as susceptibility to environmental vibrations and liquid helium pressure fluctuations), RF (such as peak surface electric and magnetic fields), and cryogenics (such as dynamic heat load). The consideration of high stability and high performance drives this present effort of exploring a mechanically strong and stable RF structure. For MFSEL structures, cylindrical tanks with multiple (n>=3) rod-shaped radial elements (see Fig. 1) were investigated as a starting point. The 3D computer simulation codes CST MWS and ANSYS were used to study electromagnetic and mechanical parameters, respectively. This paper provides the preliminary results of these types of structures.

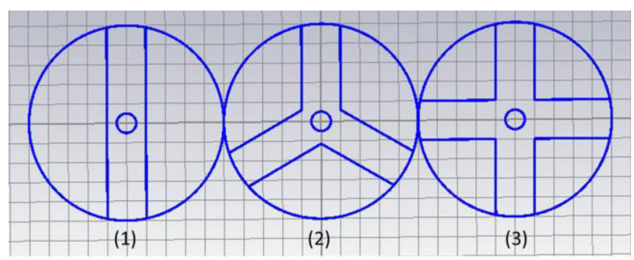


Figure 1:The general schematic of single-spoke structure (1) and MFSEL structure; three-fold (2) and four-fold (3).

## EM DESIGN

The EM design of a multi(n=3,4)-fold symmetry element-loaded structure is to be compared with a baseline structure designed for high intensity proton acceleration in the framework of accelerator-driven system efforts at IMP [4] The baseline structure is a single spoke cavity with a beta = 0.32 and a frequency of 325 MHz. The MFSEL was originally proposed for muon acceleration [5]. More recently, similar structures were studied [6]. Figure 2 shows the side-cut view of a three-fold (TFSEL) symmetry element-loaded RF structure, with geometric dimensions as used in the numerical optimization. The geometric dimensions of the four-fold (FFSEL) symmetry element-loaded RF structure are similar to that of the TFSEL structure.

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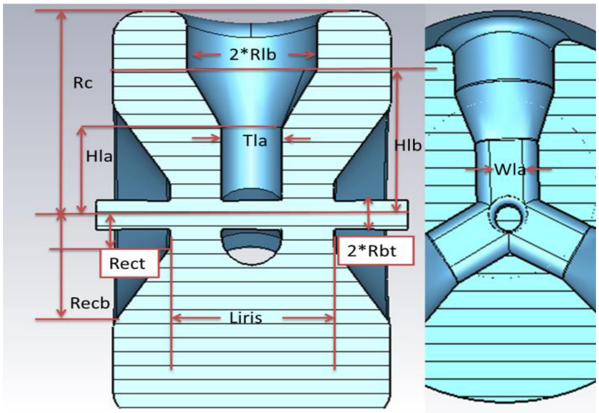


Figure 2: Side-cut views of the TFSEL RF structure indicating the main geometric dimensions used for optimizations.

Our initial design optimization was carried out with the following two conditions fixed:

- Beta
- Resonance Frequency

The main criteria was to minimize $B_{pk}/E_{acc}$, but still allow a relatively small $E_{pk}/E_{acc}$, while maintaining a relatively high G*R/Q. Convergence analyses were carried out to assure that the surface peak field accuracy was within $\pm 0.5\%$ for the chosen mesh density in CST MWS.

Figure 3 and 4 show the optimized surface electromagnetic field distribution in the TFSEL and FFSEL structures at 1 Joule of stored energy. As one can see, both new structures have TEM-like fields between each load element and the cavity wall. We adopted the same optimization strategy as used for the reference design of a single spoke cavity. A comparison of the optimized RF parameters is given in Table 1. Due to the introduction of additional loading elements in the new structures, there is an improvement of $B_{pk}/E_{acc}$ (8.4% for TFSEL, 14.6% for FFSEL) at the expense of a larger cavity diameter (7% for TFSEL, 12% for FFSEL) and smaller G*R/Q (3.8% for TFSEL, 11.5% for FFSEL).

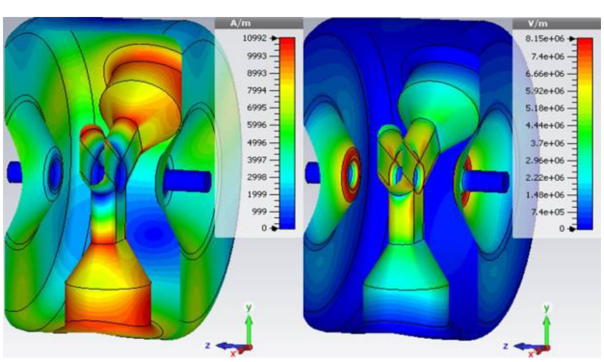

Figure 3: The optimized surface magnetic (left) and electric (right) field distribution in a TFSEL RF structure.

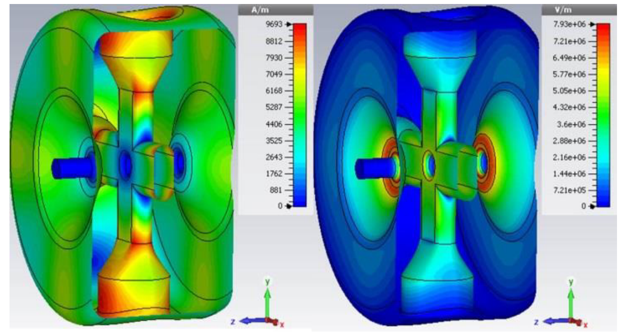

Figure 4:The optimized surface magnetic (left) and electric (right) field distribution in a FFSEL RF structure.

Table 1: Optimized RF Parameters

| Structure Type / Parameters | **Single Spoke structure** | **TFSEL structure** | **FFSEL structure** |
|---|---|---|---|
| Lc (mm) | 320 | 320 | 320 |
| Rc (mm) | 277.8 | 297.1 | 311.1 |
| f (MHz) | 325.04 | 325.05 | 324.95 |
| R/Q (Ohm) | 241 | 220 | 196 |
| G (Ohm) | 91 | 96 | 99 |
| $E_{pk}/E_{acc}$ | 3.86 | 3.59 | 3.70 |
| $B_{pk}/E_{acc}$ (mT/MV/m) | 6.65 | 6.09 | 5.68 |

$L_{eff}$=Beta*Lambda
Keep Beta=0.32 by changing Liris.
Keep frequency≅325MHz by changing cavity diameter

## MECHANICAL DESIGN

Preliminary cavity pressure sensitivity studies were performed using the ANSYS multiphysics module. The pressure-induced frequency shift (df/dp) mainly depends on the cavity shape, size, cavity wall thickness, and exterior stiffeners. In our initial model, we chose a 3.7 mm wall thickness with a 1 atm pressure load applied to the cavity external surface while keeping the beam pipe port and coupler port fixed. Fig 5 shows the total deformation profile in the single-spoke structure and FFSEL structure, respectively. The TFSEL structure has a similar deformation profile when compared to the FFSEL structure. According to the distribution of the equivalent (von-Mises) stress and the deformation in the un-stiffened structure, the existing stiffening scheme as used in Fermilab's single spoke cavity [7] was adopted as an initial study point. Fig. 6 shows the stiffeners on one side of the cavity end walls.

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Table 2: Calculated Pressure Sensitivity without and with Stiffeners

| | | **Single-Spoke structure** | | **TFSEL structure** | | **FFSEL structure** | |
|---|---|---|---|---|---|---|---|
| | | without | with | without | with | without | with |
| Max. Stress | MPa | 142 | 73 | 158 | 58 | 160 | 66 |
| Max.Deformation | mm | 0.307 | 0.127 | 0.444 | 0.126 | 0.349 | 0.168 |
| df/dp | Hz/torr | -84 | 33 | -78 | 28 | -116 | 11 |

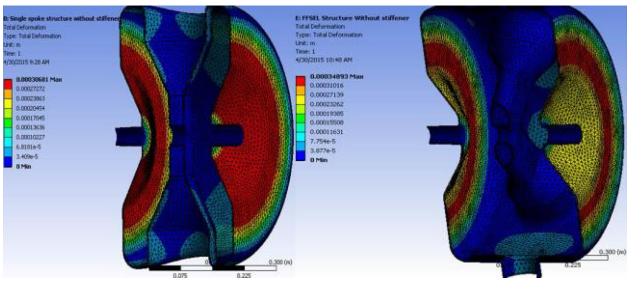

Figure 5: Total deformation profile in single spoke (left) and FFSEL structure (right).

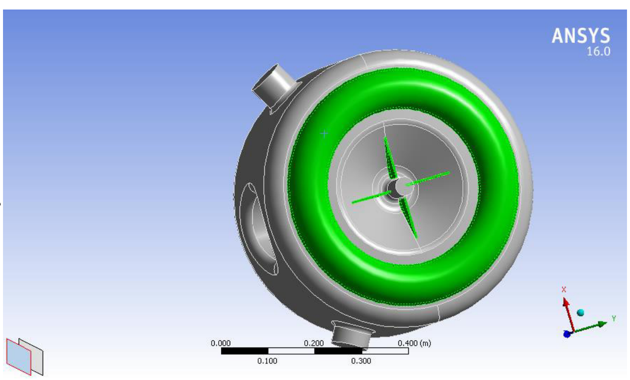


Figure 6: Stiffeners on cavity end wall (highlighted green colour).

The pressure sensitivity results calculated with and without stiffening ribs and the stiffening rings are given in Table 2. The same material thickness (4mm) and height (45mm) for stiffening ribs and same cross section area for stiffening ring were used throughout.

## CONCLUSION

Preliminary RF design and mechanical simulation studies of TFSEL and FFSEL structures have been carried out and compared to a baseline single-spoke cavity design. Further systematic design studies will continue, aiming for a minimal $B_{pk}/E_{acc}$ and df/dp. Modal analysis will also be carried out for improved mechanical stability against vibrations.

## ACKNOWLEDGMENT

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## REFERENCES

[1] J.R.Delayen et.al., Proc.1993 Particle Accelerator Conference, p1715(1993).
[2] F. Lin et al., “Progress on the Design of the Polarized Medium-energy Electron-Ion Collider at JLab”, these proceedings,TUYB3, (2015).
[3] J.C.Yang, J.W.Xia et al., Nuclear. Instrum. Math. Phys. Res. B, Volume 317 (2013) 263-265.
[4] Y.He et al. The conceptual design of injector II of ADS in China,IPAC2011,San Sebastián, Spain.
[5] R.L. Geng, “Exploring geometries of SRF cavities for a future muon collider”, unpublished (2004), http://w4.lns.cornell.edu/~grl/cav_geo_muon_collider.pdf
[6] F. He et al., “A new Cavity Design For Medium Beta Acceleration”, Proc. of SRF 2013, Paris, France (2013).
[7] G. Apollinari et al., “Development of 325 MHz Single Spoke Resonators at Fermilab,” IEEE Trans. Appl. Superconductivity. 19 (2009) 1436-1439.