INVESTIGATION OF A MULTI-CELL CAVITY STRUCTURE PROPOSED FOR IMPROVED HYDROFORMING*

Ki R. Shin[1], Yoon W. Kang, J.A. Holmes and Aly E. Fathy[1],
ORNL, Oak Ridge, TN 37831, [1]University of Tennessee, Knoxville, TN 37996, U. S. A.

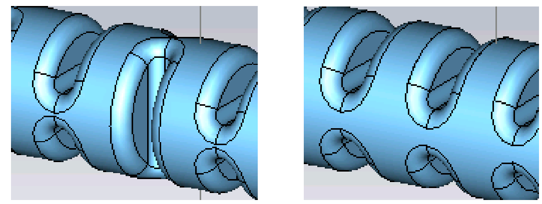
Abstract

A multi-cell cavity structure with rectangular coupling aperture between cavity cells is proposed. This investigation is to study the RF properties of such structure that may provide high yield in hydroforming. In mechanical point of view, the rectangular aperture iris may provide much improved structure quality in hydroforming since it can help to reduce the stress incurring within the sheet metal with improved structural malleability. The necking procedure can be easier because of greater perimeter in the iris geometry. Peak electric and magnetic fields per accelerating gradient may increase however, compared to traditional TESLA type elliptical cavity structure. The rectangular iris shape provides asymmetric transverse focusing per half RF period. If the horizontal and vertical rectangular irises are interleaved, the net transverse focusing may be achieved. 3D simulations with CST MWS have been carried out to analyze EM field properties and the cavity parameters.

INTRODUCTION

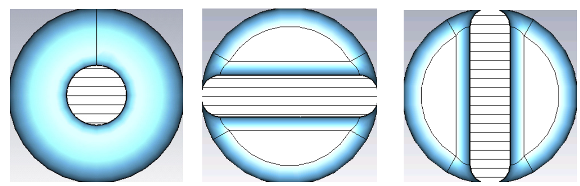
Multi-cell superconducting RF (SRF) cavities have been widely used in particle accelerators. Most SRF cavities have elliptical geometry which prevents multipacting and minimizes peak electromagnetic (EM) fields with previous experiences including TESLA [1] project. For economic reasons, seamless cavity fabrication methods have been investigated and tested [2]. Hydroforming [3] method is a main branch of this seamless method, however not yet matured because of low yield with non-uniform surface thickness. One major reason of this thickness variation originates from small cavity bore which requires huge elongation to form cavity wall in hydroforming.

Therefore, an alternative form of multi-cell cavity shape which would improve the yield of hydroforming is presented. A multi-cell cavity with coupling irises with rectangular aperture (RA) is utilized in contrast to usual circular geometry. This rectangular geometry may reduce deformation and stress on the base material during hydroforming. The focusing field near beam pipe however, is not rotationally symmetrical due to the rectangular shape. Two different types of multi-cell designs are possible. The one is to make the coupling apertures rotationally offset by 90-degrees at every other cell and the other is to have uniformly oriented apertures with no offset. That means the vertical and horizontal apertures are interleaved as shown in Figure 1 (a) or uniformly oriented as in Figure 1 (b). Figure 2 shows section views of TESLA and RA cavity.



(a) (b)

Figure 1: (a) Interleaved (b) Non-interleaved RA cavity.



(a) (b) (c)

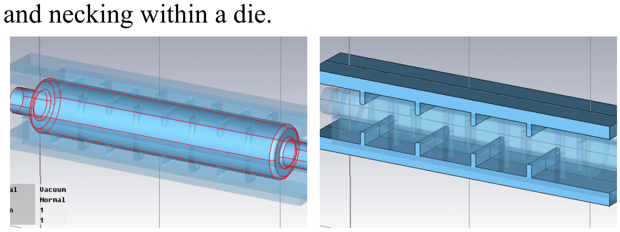
Figure 2: Section view of TESLA and RA cavity (a) TESLA (b) RA – nπ phase (c) RA – nπ +π/2phase.

HYDROFORMING AND RA CAVITY

The two basic steps for hydroforming process are necking and expansion [3]. Cavity iris geometry is shaped with necking process. Rotational necking equipments were utilized in previous TESLA experiences. Cavity body around equator is formed with expansion by internal pressure. For TESLA cavities, the material stress σ and strain ε are functions of distance R between iris to equator, and thickness t in the zenith [4] assuming constant pressure p and initial thickness t_0.

$$\sigma = \frac{pR}{2t} \quad and \quad \varepsilon = \ln\frac{t}{t_0} \tag{1}$$

Although the finalized RA cavity might increase the R near on-axis, the overall R decreases due to the rectangular iris and the increased diameter of the initial tube. Necking process in hydroforming may be simpler with this design. This may result in a better surface condition. Figure 3 shows a possible configuration of tube and necking within a die.



(a) (b)

Figure 3: (a) Initial tube (b) Necking frame.

*This work was supported by SNS through UT-Battelle, LLC, under contract DE-AC05-00OR22725 for the U.S. DOE.

ISBN 978-3-95450-115-1

RA CAVITY GEOMETRY OPTIMIZATION

Due to rotational asymmetry in geometry, RA cavity design and analysis require 3D modelling. Commonly used parameters for cavity geometry optimization in elliptical cavities are *A, B, sl, R, r, a*, and *b* as described in Figure 4 (a). To simplify fabrication process in RA cavity, the circular equator and dome condition are considered, i.e. *A*=*B*, and *a*=*b*. The dome to iris slope *sl* is not considered in this RA cavity optimization study. However, the slope may be included in future studies. The side-flat RA geometry is more similar to Low Loss (LL) [5] cavity geometry. Other parameters *r* for beam pipe radius and equator radius *R* are considered in this design study. Single cell parameters of interleaved RA cavity are compared with TESLA cavity.

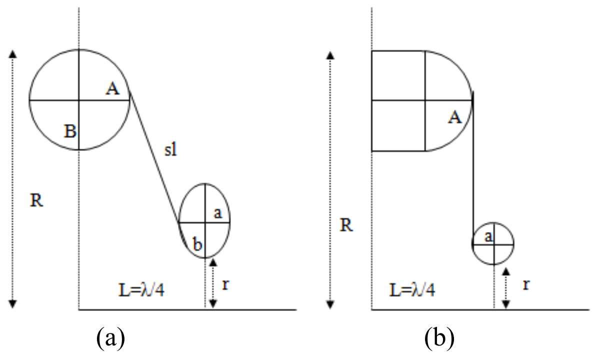


Figure 4: Cavity shape parameters : (a) TESLA (b) RA.

The result of Hpk/Eacc and Epk/Eacc ratios with respect to *a* and *A*, is shown in Figures 5 and 6. Aperture width of 35mm is used in interleaved RA cavity. The increase of peak electric and magnetic fields over the TESLA type cavity design is about 44% and 75% in RA cavity with *a*=15 and *A*=20, respectively.

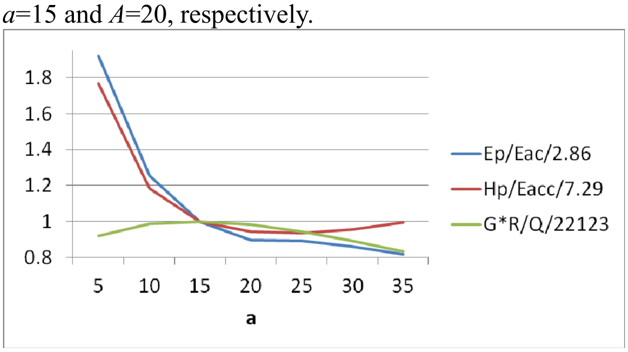


Figure 5: Hpk/Eacc and Epk/Eacc w.r.t. *a* (*r*=35, *A*=20).

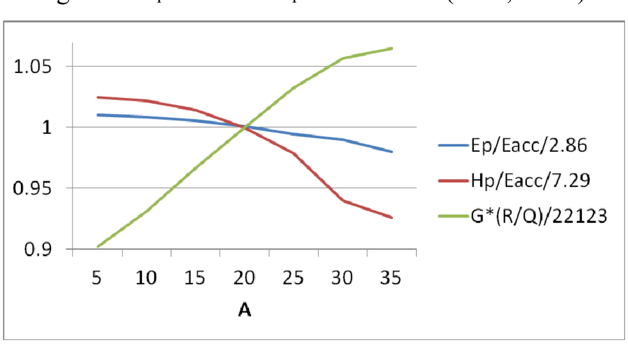


Figure 6: Hpk/Eacc and Epk/Eacc w.r.t. *A* (*r*=35, *a*=15).

Since peak EM field is highly dependent on aperture height *r*, a slightly lower *r* might help to reduce the peak field in RA cavity. Figure 7 shows peak EM field results with respect to r.

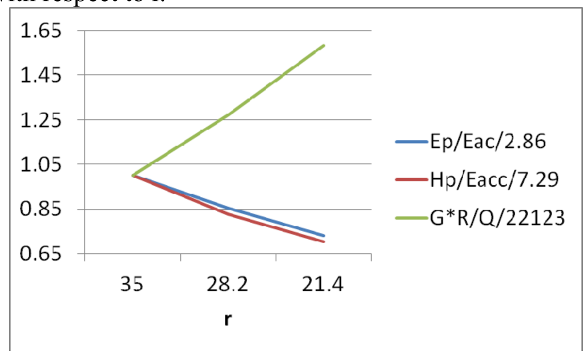


Figure 7: Hpk/Eacc and Epk/Eacc w.r.t. *r* (*a*=15, *A*=20).

CAVITY PARAMETERS

Table 1 shows comparisons of cavity parameters calculated by CST Microwave Studio [6]. Flat cavity side and rectangular iris give RA cavity higher peak field values. One interesting point of RA cavity is its high coupling factor kcc because of wider aperture. Therefore, aperture height of RA cavity can be decreased further. The peak magnetic field is a main design concern of this cavity, and the operating field gradient may have to be lowered. Figure 8 shows dispersion curves of the 9-cell TESLA and the RA cavities. Enhanced coupling factor provides higher mode separation field flatness. About 25 to 26mm aperture height of RA cavity is expected to have similar kcc and G*(R/Q) values with the TESLA cavity.

Table 1: Parameter Comparison

	Unit	*TES*	*LL*	*RA-35mm*	*RA-28mm*	*RA-21mm*
f_π	[MHz]	1300	1300	1307	1301	1299
r	[mm]	35	30	35	28.2	21.4
kcc	[%]	1.9	1.52	4.70	2.64	1.17
E_{pk}/E_{acc}	-	1.98	2.36	2.86	2.44	2.09
B_{pk}/E_{acc}	[m•mT/MV]	4.15	3.61	7.29	6.03	5.12
R/Q	[Ω]	113.8	133.7	89.1	113.2	140.1
G	[Ω]	271	284	248	248	250
G*(R/Q)	[Ω*Ω]	30840	37970	22112	28073	35025

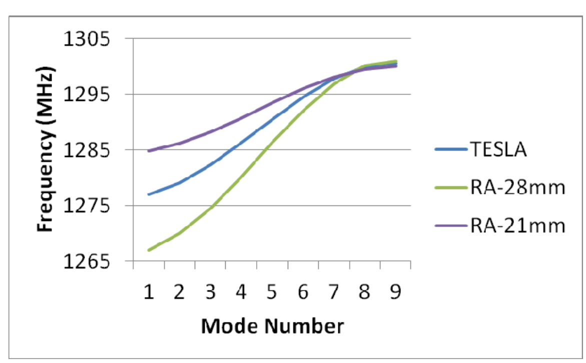


Figure 8: Dispersion curve of TESLA and RA cavity.

ISBN 978-3-95450-115-1

TE-LIKE LOW ORDER MODES

In an RA cavity, TE-like low order fundamental modes (LOMs) appear before the fundamental TM010 modes. Increased aperture width lowers cut-off frequency of fundamental waveguide modes and creates LOMs. LOM distributions are different in interleaved and non-interleaved RA cavities. Calculated LOM parameters are summarized in Table 2 and 3. Transverse shunt impedance $(R/Q)_T$ values are calculated by Panofsky-Wenzel theorem [7]. Calculated longitudinal R/Q values are quite small and not included in the Table. For Q_{TH} calculation which determines required Qext, 2MΩ/m was used for the threshold transverse impedance value. LOM damper may be required in both multi-cell designs. If beam quality is not affected much by these multiple section of TE like field, the RA cavities can still be an option.

Table 2: LOM Parameters – Interleaved 9 Cell RA

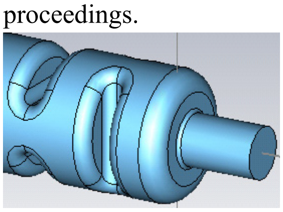
	f [MHz]	*(R/Q) T [Ω]*	*QTH*
1	955.56	6.60	11122
2	955.59	6.93	10592
3	960.35	62.70	1170
4	960.42	63.25	1160
5	965.88	41.96	1749
6	965.98	39.23	1871
7	971.09	19.02	3859
8	971.83	21.09	3480

Table 3: LOM Parameters – Non-Interleaved 9 Cell RA

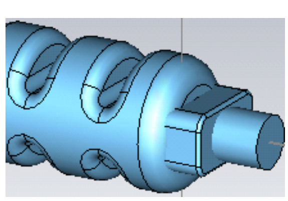
	f [MHz]	*(R/Q) T [Ω]*	*QTH*
1	828.01	0.18	407807
2	853.68	0.05	1468106
3	893.67	2.80	26216
4	944.30	3.68	19947
5	1000.10	0.48	152927
6	1058.19	42.25	1737
7	1109.09	180.77	406
8	1145.33	205.06	358

END-CELL DESIGN CHOICES

End-cell design of an RA cavity depends on manufacturing and HOM damping requirements. Since RA cavity is intended for good hydroforming yield, large end-pipe diameter may be preferred. The interleaved RA cavity fabrication may be preferred, because of more symmetrical necking pressures on both horizontal and vertical sides if a cylindrical tube is used. An interesting feature of the non-interleaved RA cavity fabrication is that rectangular tube in Figure 9 (b) may be utilized in necking and hydroforming. Detailed HOM studies and end-cell optimization will be discussed in future proceedings.



(a)



(b)

Figure 9: (a) Cylindrical (b) Rectangular End-Cell pipe.

FOCUSING FIELD ANALYSIS

In an RA cavity, electric field intensity is rotationally asymmetric on transverse plane and the net focusing can be increased. Figure 10 shows focusing electric field profiles of the TESLA cavity and the RA cavities with 35mm aperture height in one transverse plane. Field data is scaled with a stored energy of 1 Joule. For interleaved RA cavity, electric field maximum can be observed in every other cell. Over 80% of extra focusing field could be obtained with RA cavity. This focusing field increases further by reducing aperture height of RA cavity. Focusing period of TESLA and interleaved RA cavities are the same in principle, however it may be twice higher for non-interleaved RA cavity due to very small focusing field on the other transverse plane. Detailed beam simulation results are presented on this proceeding [8].

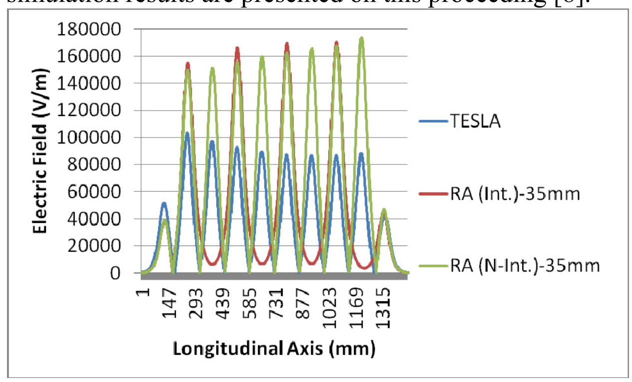


Figure 10: Focusing electric field on transverse plane.

CONCLUSIONS

To improve hydroforming process, a new RA cavity geometry is proposed. Due to rotational asymmetry, RA cavity provides enhanced electric focusing field. Peak values of electric and magnetic fields increase, however, smaller iris height and more number of cells may be possible in RA cavity due to higher cell-to-cell coupling. Calculated cavity parameters and peak field values may give a guideline for further development. Detailed studies of HOM, end-cell tuning, coupler design and multipacting effects remain for a future work.

REFERENCES

[1] B.Aune et al., "Superconducting TESLA cavities", PRST-AB Vol. 3, 2000

[2] D. Proch, "New Ways of Cavity Fabrication", Particle Accelerators, 1996, Vol.53, pp. 241-251

[3] W. Singer, "Fabrication of Hydroformed 9-cell Cavities", SRF 2007.

[4] I. Gonin et al., "Hydroforming Test of Back Extruded Niobium Tube," RF Superconductivity, Italy, 2007.

[5] J. Sekutowicz et al, "Low Loss Cavity for the 12GeV CEBAF Upgrade", JLAB TN-02-023, June 21, 2002.

[6] CST Studio Suite – www.cst.com

[7] W. Panofsky et al., Rev. Sci. Inst.27, 967(1956)

[8] J. Holmes et al., "Beam Acceleration by a Multicell RF Cavity Proposed for Improved Yield in Hydroforming", in this Proceeding.

ISBN 978-3-95450-115-1