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DEVELOPMENT OF A SUPERCONDUCTING TWIN AXIS CAVITY*

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Abstract

Superconducting cavities with two separate accelerating axes have been proposed in the past for energy recovery linac applications [1, 2]. While the study showed the advantages of such cavity, the designs present serious fabrication challenges. Hence the proposed cavities have never been built. The new design, twin axis cavity, proposed by Jefferson Lab and optimized by Center for Accelerator Science at Old Dominion University, allows similar level of engineering and fabrication techniques of a typical elliptical cavity. This paper describes the preliminary results of LOM and HOM spectrum, engineering and fabrication processes of a single cell prototype of the twin axis cavity.

ELECTROMAGNETIC DESIGN

Optimization

The ultimate design goal of the twin axis cavity is a fully optimized 'multicell' cavity. A single cell cavity has more flexibility than a multicell cavity as far as optimizing the rf properties. However our single cell prototype was designed under the same constraints of multicell cavity most notably limiting the cavity length to a half wave length. Therefore, the single cell cavity with beam pipes has a frequency 1484 MHz. The intended frequency of multicell cavity is 1497 MHz which is Jefferson Lab's CEBAF operating frequency. Figure 1 is showing the dumbbell design of twin axis cavity [3].

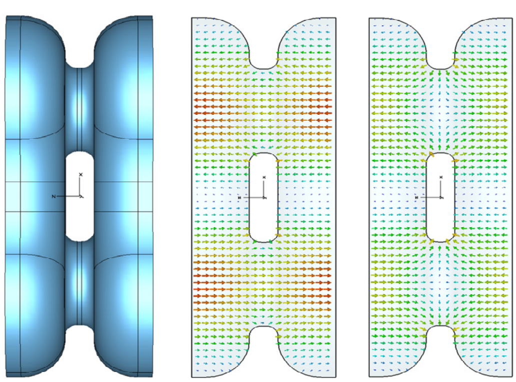

Figure 1: Dumbbell design and its 0 mode and π mode electric field distribution.

As a new design, optimization focused not only on the cavity performance parameters but also on manufacturability and minimizing multipacting. The property of the optimized cavity is shown in the Table 1 and the single cell cavity with beam pipes is shown in Fig. 2.

Table 1: RF Properties of Twin Axis Cavity [2]

Property	Value	Unit
Frequency	1484	MHz
E_p/E_{acc}	2.5	-
B_p/E_{acc}	5.34	mT/(MV/m)
R/Q	63	Ω
G	315	Ω
LOM	1146	MHz
HOM	1872	MHz

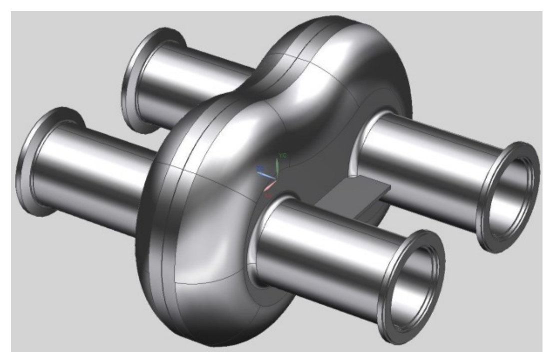

Figure 2: Single cell twin axis cavity.

LOM and HOM Spectrum

The EM design provides the closest LOM and HOM well separated from the operating frequency. For each mode, R/Q was calculated to see its effect on the beam. Depending on the field components on the beam axis, there are longitudinal R/Q and transverse R/Q on X or Y plane.

The accelerating mode's R/Q is

$$\frac{R}{Q}=\frac{\left[\int_{-\infty}^{+\infty}E_z\left(z,x=b,y=0\right)\mathrm{e}^{-j\omega z/c}\mathrm{d}z\right]^2}{\omega U}$$

where E_z is a z component of electric field, b is a beam axis location, ω is the mode's frequency and U is the stored energy in the cavity. In case of deflecting modes, E_z is replaced by E_x or E_y. Also the magnetic field contribution is added as shown below.

$$\frac{R}{Q}=\frac{\left[\int_{-\infty}^{+\infty}\left(E_x+jcB_y\right)\mathrm{e}^{-j\omega z/c}\mathrm{d}z\right]^2}{\omega U}$$

where electric and magnetic fields are still evaluated on the beam axis.

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The R/Q of the LOM is slightly higher than that of operating mode. A monopole field distribution of the LOM suggests a simple coaxial probe in the center of the cell can strongly couple to this mode without disturbing operating mode. The other option is a magnetic coupler at the equator. The electric field profile comparison between LOM and the operating mode is shown Fig. 3.

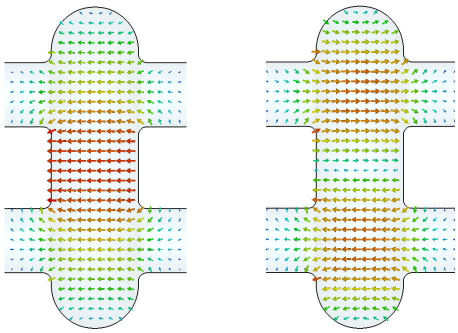

Figure 3: Electric field profile of LOM (left) and 1484 MHz operating mode (right).

The HOM field profiles were also examined. The R/Q of accelerating HOMs are relatively low. However several deflecting modes present high R/Q. Examples of those deflecting modes are shown in Fig. 4.

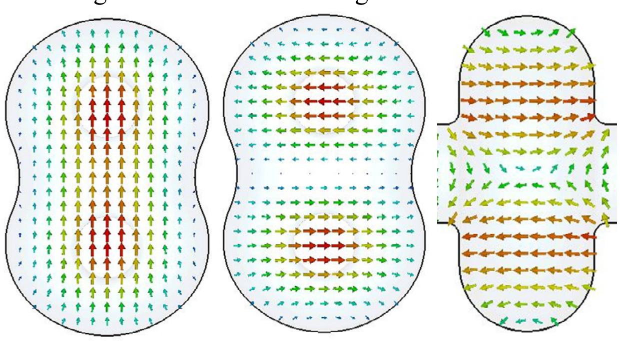

Figure 4: HOM electric field profile of 1934 MHz (left), 2022 MHz (middle), and 2060 MHz (right).

To couple all planes, two conceptual hook couplers were modeled. The hooks are oriented both (X and Y) directions as shown in Fig. 5.

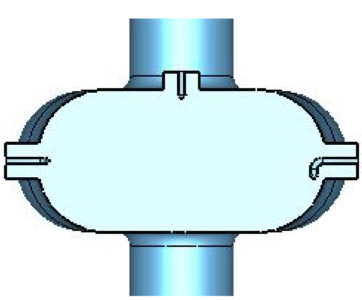

Figure 5: Conceptual LOM and HOM couplers.

The resulting external Q values with all three LOM/HOM couplers are summarized in Table 2. The coupler design and location will be finalized after repeating the same study with the multicell cavity.

Table 2: LOM/HOM Spectrum and External Q

Loaded Frequency (MHz)	R/Q X (Ohm)	R/Q Y (Ohm)	R/Q Z (Ohm)	External Q
1101			66	4.89E+03
1483			63	9.50E+10
1876		17		9.04E+03
1883		19		9.40E+02
1885			11	3.83E+03
1934	119			1.50E+05
2010	112			5.98E+03
2022		109		2.72E+06
2060		107		2.12E+11
2272	9			2.84E+09
2378	9			1.66E+02
2411	1	7	6	2.69E+02
2476	1	7	5	6.85E+04
2485	1	1		1.48E+04
2576				1.73E+04
2605			13	1.47E+05
2679	1			1.73E+03
2688				4.73E+04
2785	19			4.99E+03
2791	1		6	7.58E+02
2822		5		4.09E+02
2843				1.27E+05
2849	3			2.47E+02
2851	3		3	6.86E+09
2861		6		1.09E+05
2883		13		2.03E+10
2895	8			1.03E+05
2913		46		4.27E+06
2920		33		1.13E+12
2934	41			3.28E+08
2965	28			2.53E+04
2979	16			2.94E+03
2990				1.48E+03
3006				1.31E+05
3030				1.14E+05

MECHANICAL DESIGN

A unique goal of the mechanical design of twin axis single cell cavity is to make the design compatible with Nb_3Sn deposition which is being developed in Jefferson Lab [4,5]. The past test at Jefferson Lab indicates that the niobium become significantly softer after high temperature heat treatment. The modulus of elasticity (Young's modulus) and allowable stress were derived from the stress strain curve of the high temperature treated niobium [6]. The deposition chamber allows only niobium so the cavity flange was also made of niobium instead of typical

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niobium titanium or stainless steel. The following is the value used for the mechanical study.

- Modulus of elasticity 30 GPa.
- Poisson ratio 0.38
- Yield strength 30 MPa

For a single cell prototype we used the maximum dewar pressure, 1000 torr to maintain the design geometry at 2K test and the mechanical integrity of the cavity. Obviously the multicell cavity will use much higher pressure and more rigorous analyses following the boiler and pressure vessel code. The final design needed a simple stiffener to avoid a deflection of the flat area between the beam pipes. Figure 6 shows the design achieving the mechanical stability and sowing a limited local yield far away from the cavity.

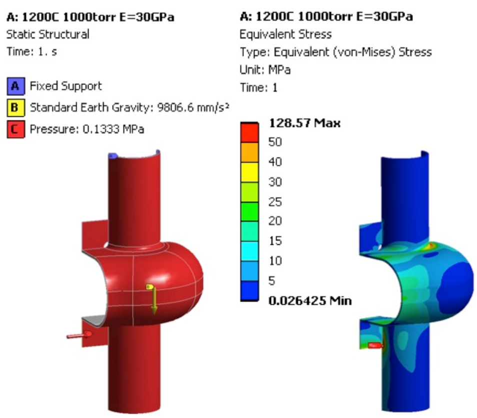

Figure 6: Stress analysis showing a quarter model.

FABRICATION

The forming die was machined following the final cavity design. Counteraction against spring back was not considered for the prototype single cell die since the purpose is to see how comparable the twin axis cavity forming is compared to a typical cavity forming.

A 150 ton hydraulic press was used to form the half cells (Fig. 7). The copper blank was used to test the die before forming niobium blanks.

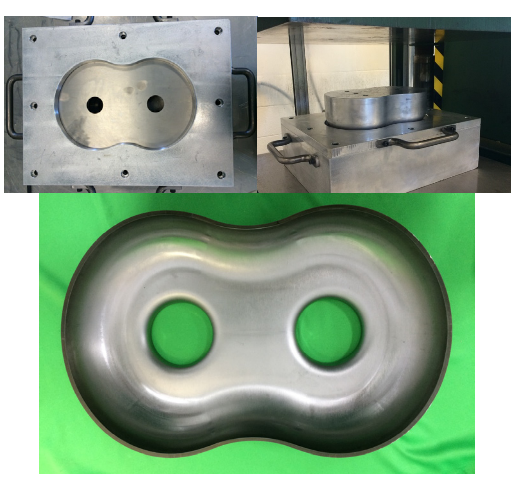

Figure 7: Nb blank placed in the die (top left), die set under press (top right) and stamped half cell (bottom).

The half cell's relatively large flat surface serves an excellent datum for trimming of the equator and iris. Traditionally a trimming fixture similar to a forming die is used for trimming. But this flat feature makes it simple and economic to trim using wire electrical discharge machine (EDM) as shown in Fig. 8.

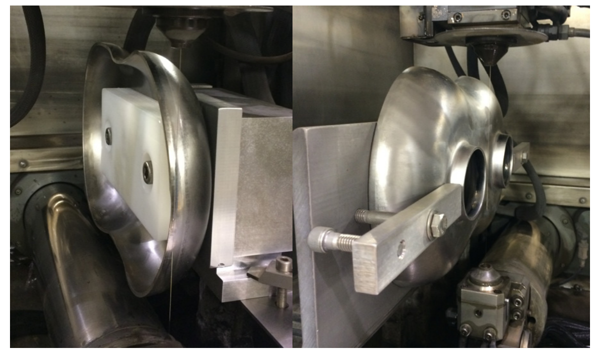

Figure 8: Wire EDM trimming of equator (left) and iris (right).

CONCLUSION AND PLAN

The advantage of twin axis cavity in energy recovery linac was shown but the fabrication of such design was never materialized. Design optimization considering fabrication proved the twin axis cavity can be fabricated with the current cavity fabrication technique.

The twin axis single cell cavity is expected to be complete in a month and will be tested before the end of 2016.

The optimization of a multi cell cavity (Fig. 9), completing LOM/HOM spectrum and damping scheme is also on-going.

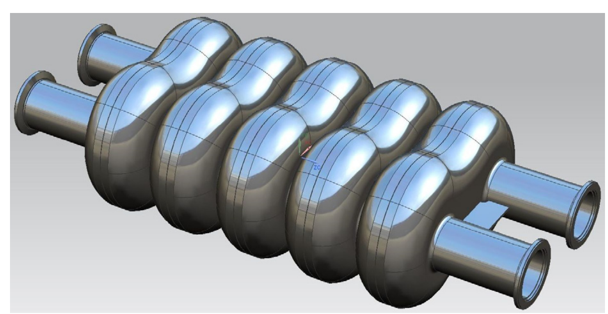

Figure 9: Multicell twin axis cavity.

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