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ELECTROMAGNETIC DESIGN OF A SUPERCONDUCTING TWIN AXIS CAVITY*

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Abstract

The twin-axis cavity is a new kind of rf superconducting cavity that consists of two parallel beam pipes, which can accelerate or decelerate two spatially separated beams in the same cavity. This configuration is particularly effective for high-current beams with low-energy electrons that will be used for bunched beam cooling of high-energy protons or ions. The new cavity geometry was designed to create a uniform accelerating or decelerating fields for both beams by utilizing a TM_{110} dipole mode. This paper presents the design rf optimization of a 1497 MHz twin-axis single-cell cavity, which is currently under fabrication.

INTRODUCTION

The idea of utilizing elliptical shaped rf superconducting accelerating structures with two beam pipes intended for Energy Recovery Linacs (ERLs) applications was first proposed by Noguchi and Kako in 2003 [1]. A similar concept was revisited by Wang, Noonan, and Lewellen in 2007 [2, 3] and recently [4] for based ERL applications. The new proposed superconducting twin-axis cavity allows energy recovery by accelerating and decelerating beams within the same cavity in two beam pipes. The accelerated beam is physically separated from the parallel accelerated/decelerated beam, but interacts with the same rf dipole mode. In an ERL for instance, the low energy beam delivered from the source can be injected into the cavity without requiring a complicated merger structure and thus additional beam line space to bend the beam, while maintaining a small beam emittance.

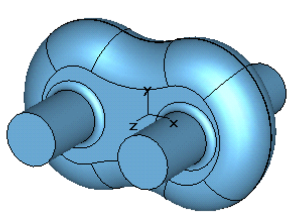

Figure 1: Twin axis cavity.

The new twin-axis cavity geometry, shown in Fig. 1, is designed to create a uniform field for both beams by operating in the TM_{110} rf dipole mode. The electromagnetic fields in the two beam pipes are axially symmetric with a 180 degree phase offset. The on-axis electric field and magnetic field at the cross sectional planes are shown in Fig 2.

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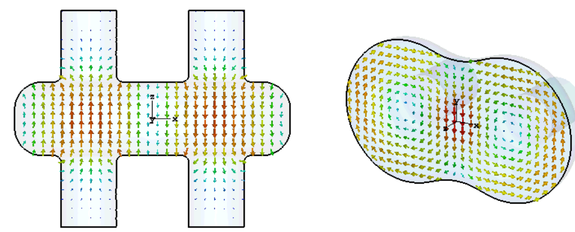

Figure 2: Electric (left) on-axis and magnetic (right) field profile at the cross section of the twin axis cavity.

The beam pipe axis position has been optimized to maximize the on-axis longitudinal electric field component ($E_z(z)$) trying to symmetrize the field across the beam aperture as best as possible, while minimizing the transverse fields ($E_x(z)$ and $H_y(z)$). The optimization of the cavity shape focused on minimizing the transverse component without degrading the accelerating component. Note that the magnetic field is strong at the center of the cavity unlike in conventional accelerating cavities using a TM monopole mode, where the peak surface magnetic field is at the equator.

DESIGN OPTIMIZATION

The initial design of the twin axis cavity was a cylindrical shaped geometry as shown in Fig. 3(a), which then evolved into a racetrack-shaped design with a compressed mid-section. The design has been modified to improve the rf properties, primarily to reduce the peak surface magnetic field.

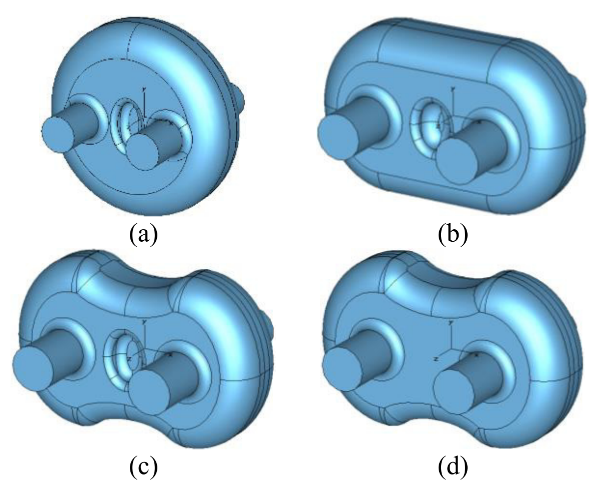

Figure 3: Design evolution of twin axis cavity geometry.

The initial designs (Fig.3(a)–(c)) includes an inward bump to enforce uniformity of the longitudinal fields in each of the two beam pipe. This resulted in an increase in the peak magnetic field. The racetrack-shaped designs

(Fig.3(b)–(d)) allow wider separation between the beam pipes generating a more monopole-like electric field along the two beam pipes. The rf properties of the four designs are given in Table 1. Design shown in Fig. 4(d) with modified racetrack-shape resulted in an almost monopole-like electric field after the removal of the inward bump. Removal of inward bump reduced the peak surface magnetic field by 30%. This geometry resembles the two combined TM_{010} cavities with two beam pipes.

Table 1: RF Properties of Cavities Shown in Fig. 3

Parameter	(a)	(b)	(c)	(d)	Units
E_p/E_{acc}*	2.33	2.22	2.2	2.22	
B_p/E_{acc}*	7.72	7.17	7.1	5.05	mT/ (MV/m)
$[R/Q]$	58	66	68	69	Ω
G	328	323	305	318	Ω
R_tR_s	1.89	2.12	2.1	2.2	$\times 10^4\ \Omega^2$
LOM	852,1456	974	1044	1157	MHz
HOM	1774	1819	1815	1841	MHz

*At E_{acc} = 1 MV/m

In the final design the peak electric field is reasonably uniform. In that geometry the mode of interest is the second eigenmode with only one lower order mode (LOM), which is the TM_{010} mode. The frequency separation of the operating mode of 1497 MHz with both LOM and the nearest higher order mode (HOM) with is about 340 MHz. The other polarization of the operating mode is shifted to a higher frequency.

SINGLE CELL DESIGN FOR A MULTI-CELL CAVITY

As the twin axis cavities are intended for applications in energy recovery linacs, the practical solution would be the use of such a cavity in a multi-cell structure. The final single-cell design was optimized with the intention of using it in a multi-cell cavity.

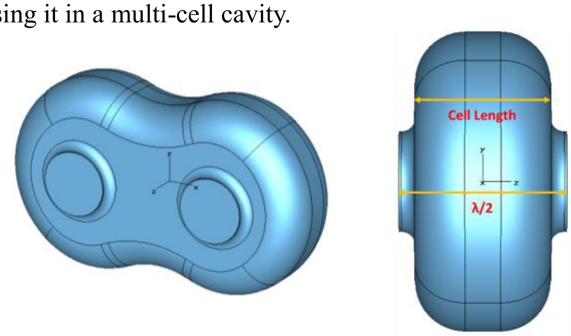

Figure 4: 1497 MHz twin axis single-cell cavity intended for multi-cell structure.

The single cell cavity intended for a multi-cell cavity was optimized with fixed iris-to-iris cavity length of half wavelength (100.2 mm) as shown in Fig. 4. The cell length was optimized including the curvature at the iris region. The dependence of cavity cell length with varying beam aperture on the electric and magnetic surface fields, and shunt impedance are shown in Fig. 5. As the cell length increases B_p/E_{acc} drops, while E_p/E_{acc} increases as the iris curvature is reduced in order to keep the cavity length constant. This also reduces R_tR_s. Therefore, a final cavity cell length was selected to be 81.2 mm with an iris curvature of 8.0 mm.

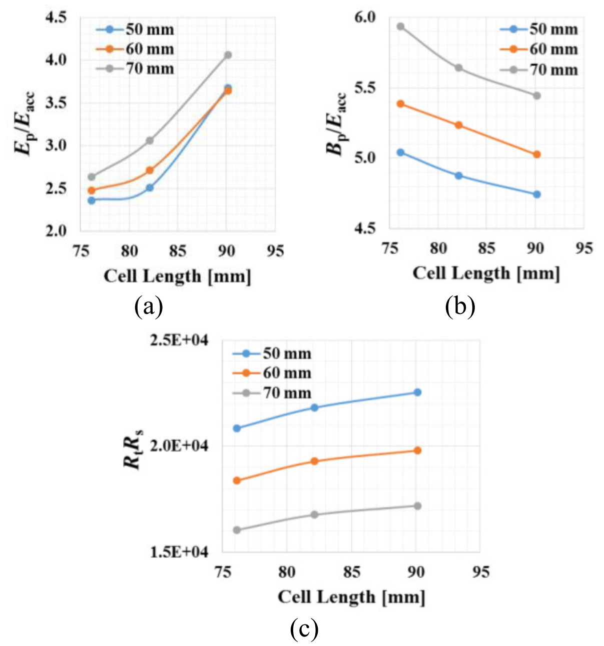

Figure 5: Dependence of (a) E_p/E_{acc}, (b) B_p/E_{acc}, and (c) R_tR_s with varying beam aperture radii and cavity cell length.

Cell-to-cell Coupling

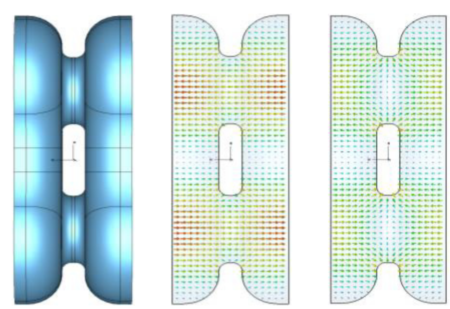

Figure 6: Twin axis cavity dumbbell (left) with 0 mode (middle) and π mode (right).

A study of the coupling coefficient was done to determine the appropriate beam aperture. The coupling coefficient (k_{cc}) was calculated using the 0 mode and the π mode as shown in Fig. 6. The corresponding k_{cc} values are shown in Fig. 7. The k_{cc} of CEBAF 7-cell 1497 MHz is 1.55 %, therefore a similar k_{cc} was chosen for the twin axis cavity; hence a 60 mm beam aperture is selected for the center cells in the multi-cell cavity. However, based on HOM requirements a larger beam aperture may be required for the end-cells.

The twin-axis cavity with 60 mm beam aperture was selected as the optimum design aperture for the single-cell cavity intended for a multi-cell structure. The design frequency of 1497 MHz of the single cell cavity is achieved with no beam pipes, where the addition of the beam pipes drop the frequency to 1484 MHz. The properties of the final design are given in Table 2.

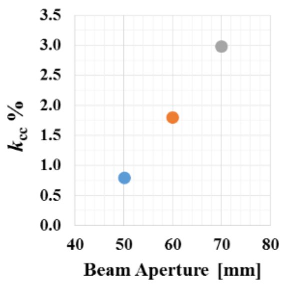

Figure 7: Coupling coefficient (k_{cc}) with varying beam aperture.

Table 2: Cavity parameters and rf properties of the 1497 MHz single cell twin axis cavity.

Parameter	Value	Units
Cavity height	202.5	mm
Cavity width	300.0	mm
Cavity length	100.13	mm
Cell length	81.13	mm
Iris curvature	8.0	mm
Beam aperture	60.0	mm
Beam axis separation	136.5	mm
V_{acc}	0.1	MV
E_p/E_{acc}*	2.68	
B_p/E_{acc}*	5.5	mT/(MV/m)
$[R/Q]$	60.1	Ω
G	320.8	Ω
R_tR_s	1.93×10^4	Ω^2
LOM	1103	MHz
Nearest HOM	1806	MHz
V_t	26.4	V
*At E_{acc} = 1 MV/m		

The single cell cavity was designed without flat surfaces around the iris region to improve the fabrication. The current twin-axis geometry is therefore favourable for manufacturing compared to the previous similar cavity models [1-3]. The cavity is currently being fabricated at Jefferson Lab [5].

MULTIPACTING ANALYSIS

Elliptical cavities show multipacting levels at the equator region depending on the cell shape. Similar multipacting levels were observed in the twin axis cavity as shown in Fig. 7. The multipacting levels were simulated using the Track3P code in SLAC ACE3P suite [6].

The design shown in Fig. 8 has a rounding of 30 mm at the equator. The multipacting levels were observed at very low gradient as shown in Fig. 9. The impact energy of the resonant particles are in the range of 60 eV to 240 eV which falls in the region where the secondary emission yield for niobium is greater than 1. Therefore, the rounding of the equator region is increased to 40 mm, and simulation shows no multipacting levels up to accelerating gradient of 15 MV/m.

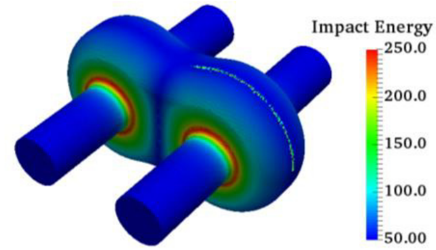

Figure 8: Position of the resonant particles on the twin axis cavity as a function of impact energy in units of eV.

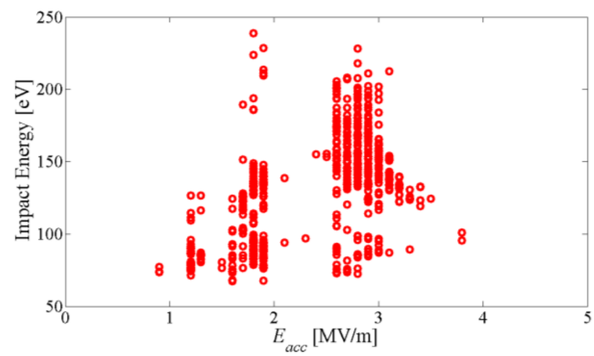

Figure 9: Impact energy of resonant particles as a function of accelerating gradient (E_{acc}).

CONCLUSION

The preliminary design of the twin axis cavity has been optimized as a single cell design intended for a multi-cell cavity. At present, the single cell cavity is being fabricated as a proof-of-principle design to study the rf properties. The design of a full multi-cell structure for an ERL, requires an extensive study in HOM analysis. The field configuration of the operating mode with low magnetic field at the equator would be advantageous in designing on-cell HOM couplers for this cavity design.

REFERENCES

[1] S. Noguchi and E. Kako, in *Proc. SRF 2003*, Lubeck, Germany, 2003, p.317.
[2] C.-X. Wang, J. Noonan and J. W. Lewellen, in *Proc. ERL 2007*, Daresbury, UK, 2007, p.18.
[3] C.-X. Wang, in *Proc. SRF 2007*, Beijing, China, 2007, p.641.
[4] R. Ainsworth *et. al.*, *Phys. Rev. Accel. Beams* **19**, 083502, 2016.
[5] H. Park, *et. al.*, presented at LINAC2016, Lansing, MI, USA, 2016, paper THPLR037.
[6] K. Ko, *et. al.*, in *Proc. LINAC 2010*, Tsukuba, Japan, 2010, p.1028.

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