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DESIGN OF SUPERCONDUCTING PARALLEL-BAR DEFLECTING/CRABBING CAVITIES WITH IMPROVED PROPERTIES*

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Abstract

The superconducting parallel-bar cavity is a deflecting/crabbing cavity with attractive properties, compared to other conventional designs, that is being considered for a number of applications. All designs to-date have been based on straight loading elements and rectangular outer conductors. We present new designs of parallel-bar cavities using curved loading elements and circular or elliptical outer conductors, with significantly improved properties such as reduced surface fields and wider higher-order mode separation.

INTRODUCTION

The superconducting parallel-bar cavity [1] is currently being considered as a deflecting cavity for the Jefferson Lab 12 GeV upgrade and as a crabbing cavity for the proposed LHC luminosity upgrade. It is also being considered for the Project-X deflecting cavity and as one of the options for the ELIC crab cavity.

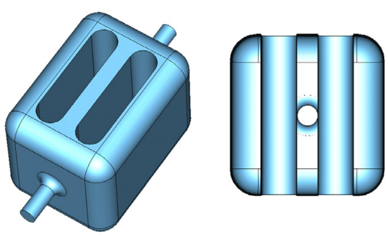

Figure 1: 499 MHz rectangular shaped superconducting parallel-bar cavity (left) and vertical cross section of the design (right).

In the parallel-bar cavity shown in Fig. 1 the beam is deflected or crabbed by the transverse electric field between the parallel bars. The cavity design with rectangular outer conductor has two TEM-type parallel bars connecting the top and bottom surfaces, which oscillate in opposite phase generating the transverse electric field. The curved edges of the cavity introduce a small vertical magnetic field along the beam line that opposes the net deflection. However this contribution from the magnetic field is very small. The parallel-bar geometry has two fundamental degenerate modes; the other fundamental mode is an accelerating mode in which the bars oscillate in phase. The two fundamental degenerate modes in the geometry are separated by the inclusion of beam pipe and curved edges.

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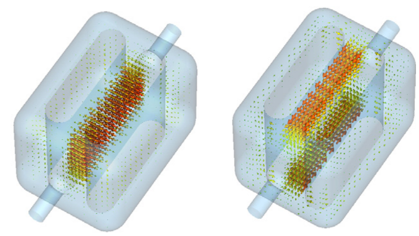

Figure 2: Electric field (left) and magnetic field (right) profiles for the rectangular shaped parallel-bar cavity.

The compact parallel-bar design operates at low frequency where the length and height are of the order of $\lambda/2$. The field orientation in the rectangular parallel-bar cavity in Fig. 2 shows the concentrated transverse electric field between the bars and the magnetic field that loops around the bars at top and bottom surfaces.

The design is optimized to meet the requirements and dimensional constraints of the 499 MHz rf separator required for the Jefferson Lab 12 GeV upgrade. The deflecting cavity is expected to deliver the 11 GeV beam to the three experimental halls simultaneously. The properties of the optimized rectangular shaped parallel-bar cavity are listed in Table 1. The small frequency separation between the two fundamental modes could make the damping of the accelerating mode difficult in high current applications. This may also result in mixing of the two fundamental modes. In addition the design has low peak surface electric field with slightly higher peak surface magnetic field. For tolerable operating peak surface fields of E_P=35 MV/m and B_P=80 mT the field balancing ratio (B_P/E_P) is 2.3 mT/(MV/m). For the rectangular shaped design B_P/E_P is 3.62 mT/(MV/m). Furthermore the large flat surfaces of the rectangular shaped cavity make the design prone to deformations due to radiation and liquid helium pressure.

The rectangular shaped parallel-bar geometry can be modified into cylindrical and elliptical shapes to eliminate the above mentioned limitations. Detailed studies of the cylindrical and elliptical geometries have shown to have improved electromagnetic and mechanical properties. The properties of three different design configurations of the cylindrical parallel bar geometry are discussed in detail in this paper.

NEW PARALLEL-BAR DESIGNS

The 499 MHz cylindrical shaped parallel-bar designs with straight bars, curved bars and bars merged to the side walls shown in Fig. 3 are optimized for lower peak surface fields.

Table 1: Properties of the Parallel-bar Structures of (A) Rectangular Shaped (B) Cylindrical Shaped with Straight Bars (C) Cylindrical Shaped with Curved Bars (D) Cylindrical Shaped with Bars Merged on to the Walls

Parameter	**(A)** Fig. 1	**(B)** Fig. 3	**(C)** Fig. 3	**(D)** Fig. 3	**KEK Cavity**[2]	**Units**
Frequency of π mode	499.2	499.0	499.0	499.0	508.9	MHz
$\lambda/2$ of π mode	300.4	300.4	300.4	300.4	294.8	mm
Frequency of 0 mode	517.8	622.8	794.0	911.5	-	MHz
Frequency of near neighbour mode	517.8	622.8	736.0	753.1	410.0	MHz
Frequency of lower order mode	-	-	-	-	410.0	MHz
Cavity length	394.4	345.0	345.0	345.0	299.8	Mm
Cavity diameter / width	290.0	319.9	281.2	285.2	866.0	Mm
Cavity height	304.8	-	-	-	483.0	Mm
Bars width at waist	67.0	65.0	65.0	65.0	-	Mm
Bars length	284.0	275.0	275.0	275.0	-	Mm
Bars height / curved height	304.8	300.0	272.7	275.9	-	
Aperture diameter	40.0	40.0	40.0	40.0	130.0	Mm
Deflecting voltage (V_T^*)	0.3	0.3	0.3	0.3	0.3	MV
Peak electric field (E_P^*)	1.85	2.03	2.4	2.63	4.24	MV/m
Peak magnetic field (B_P^*)	6.69	6.33	5.6	5.72	12.23	mT
B_P^* / E_P^*	3.62	3.11	2.31	2.18	2.88	mT/(MV/m)
Energy content (U^*)	0.031	0.033	0.034	0.039	-	J
Geometrical factor	67.96	63.98	83.2	85.5	220	Ω
$[R/Q]_T$	933.98	875.7	839.5	735.6	46.7	Ω
$R_T R_S$	6.3×10^4	5.6×10^4	7.0×10^4	6.3×10^4	1.03×10^4	Ω^2

At $E_T^* = 1$ MV/m

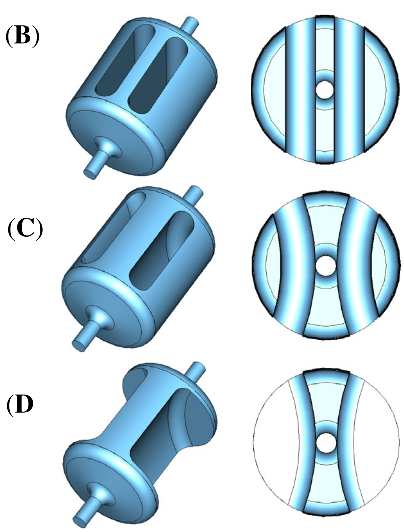

Figure 3: 499 MHz cylindrical shaped superconducting parallel-bar cavity with straight parallel bars (top), curved parallel bars (center) and bars merged to the side wall (bottom) with corresponding vertical cross sections.

As shown in Table 1 the peak surface electric field for each design increased however the peak surface magnetic field has reduced. The curved bars with a wider separation at the connecting plane to the outer conductor improve the surface magnetic fields but the rectangular shape is desirable for lower surface electric fields. Geometries with curved bars have balanced surface fields with B_P/E_P closer to 2.3 mT/(MV/m).

The $[R/Q]$ decreased for the cylindrical shaped geometries. However the substantial increase in the geometrical face gives higher R_TR_S, especially in the design with curved bars reducing the input power required to operate the cavity.

Fig. 4 shows other variants of the parallel-bar cavity that we have investigated for other applications: a 400 MHz crabbing cavity for a possible LHC upgrade and a 750 MHz crabbing cavity for an electron-ion collider.

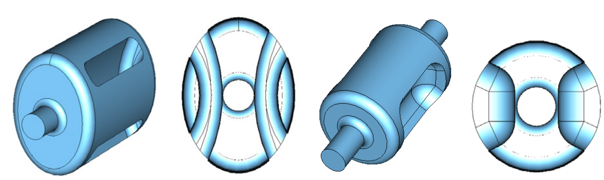

Figure 4: 400 MHz (left) and 750 MHz (right) crabbing cavities.

HIGHER ORDER MODE PROPERTIES

The $[R/Q]$ values for higher order modes (HOM) up to 2 GHz are shown in Fig. 5. Unlike other conventional cavity geometries, the HOMs in the parallel-bar cavity are categorized [3] as accelerating modes (E_Z), modes with horizontal deflection (E_X, H_Y), modes with vertical deflection (E_Y, H_X) and modes with longitudinal magnetic field that doesn't coupled to the beam.

The non-existence of any lower order modes in all designs is an attractive feature of this geometry. From the graphs it can be clearly seen that the number of HOMs are less in the cylindrical designs compared to the rectangular design. The frequency separation between the fundamental modes increased by more than 200 MHz in the cylindrical shaped geometry with curved parallel bars.

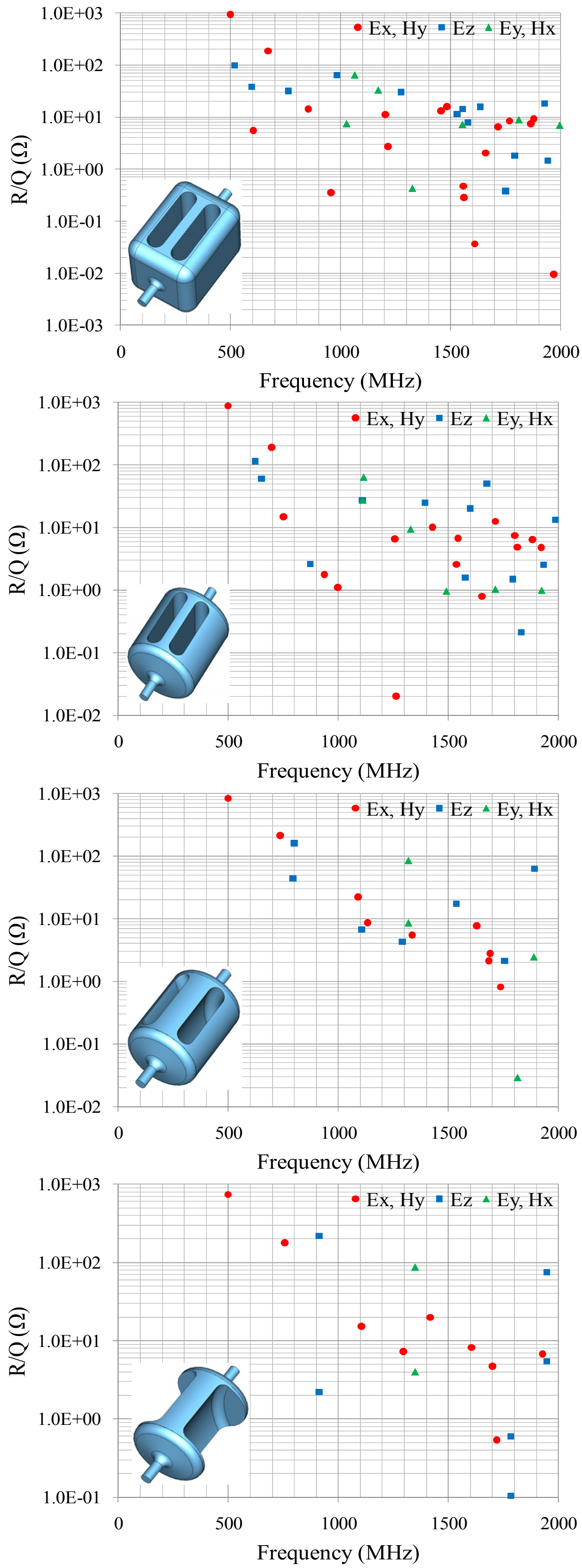

Figure 5: [R/Q] values for the rectangular shaped and cylindrical shaped parallel-bar cavities.

The wider mode separation eases the HOM damping in these designs. In the design with bars merged on to the walls, the HOM modes trapped near the beam pipe can be damped with couplers placed at the side walls.

FIELD NON-LINEARITY ANALYSIS

The variation of the transverse deflection is analyzed off the beam axis in horizontal (along x) and vertical (along y) directions, for both rectangular shaped design and cylindrical shaped design with curved bars. As shown in Fig. 6 the change in normalized transverse voltage is higher for the cylindrical shaped design. However in both the designs the beam sees a uniform field near the beam axis with small deviations in V_T.

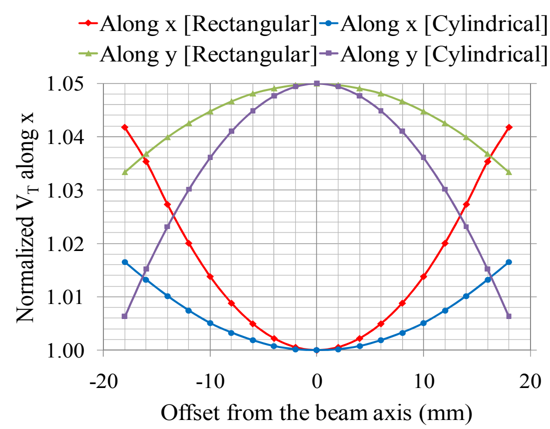

Figure 6: Normalized transverse deflecting voltage variation in x and y directions for the rectangular shaped design and cylindrical shaped design with curved bars.

CONCLUSIONS

The cylindrical shaped parallel-bar designs are analyzed in detail and the improved properties have been identified. The compact designs have attractive properties over the rectangular shaped the parallel-bar cavity. The cylindrical shaped parallel-bar cavity with the curved bars has the best properties of all the designs.

The balanced surface fields allow the cavity to operate at higher deflecting voltage. Fewer HOMs with wider separation makes the damping of those modes more efficient. Multipacting studies are underway.

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