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DESIGN AND DEVELOPMENT OF SUPERCONDUCTING PARALLEL-BAR DEFLECTING/CRABBING CAVITIES*

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Abstract

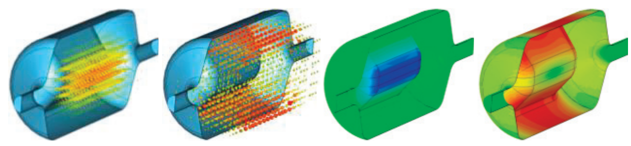
The superconducting parallel-bar cavity is a deflecting/crabbing cavity with attractive properties that is being considered for a number of applications. We present the designs of a 499 MHz deflecting cavity developed for the Jefferson Lab 12 GeV Upgrade and a 400 MHz crabbing cavity for the LHC High Luminosity Upgrade. Prototypes of these two cavities are now under development and fabrication.

INTRODUCTION

The parallel-bar deflecting/crabbing cavity [1] has evolved with improved properties from a rectangular design with cylindrical parallel bars into a design with a cylindrical outer conductor with trapezoidal shaped parallel bars [2]. The design has low peak surface fields for a given net deflection which is favorable for superconducting cavity designs. Also the design has balanced peak surface electric and magnetic fields. The trapezoidal shaped parallel bars allow the design to be optimized to achieve balanced surface fields with a higher net deflection for a given design frequency and beam aperture. The high shunt impedance gives low power dissipation through the cavity surface. This geometry is more resistant to mechanical deformations due to liquid He pressure and mechanical vibrations. One of the unique properties of the parallel-bar cavity design is that the fundamental deflecting/crabbing mode is the lowest mode present in the geometry with the nearest mode widely separated at 1.5 times the fundamental mode frequency [3]. The high degree of symmetry of the designs allows more uniform fields across the beam aperture.

The electric and magnetic field content and surface fields for the parallel-bar cavity design at 499 MHz frequency with a beam aperture diameter of 40 mm are shown in Fig. 1.

The parallel-bar deflecting/crabbing cavity is currently being considered for number of applications. Primarily as the 499 MHz rf separator for the Jefferson Lab 12 GeV upgrade and the 400 MHz crabbing cavity for the proposed LHC luminosity upgrade. The two designs are being optimized to meet the requirements and specifications of each application, and are in the initial phase of prototype fabrication and testing. Recently this



(a) (b) (c) (d)

Figure 1: (a) Electric and (b) magnetic field profile and surface (c) electric and (d) magnetic fields of the parallel-bar cavity.

design is also being considered as the crabbing cavity for the proposed Medium Energy Electron-Ion Collider (MEIC) at Jefferson Lab. This paper discusses the current status on the design and development of the 499 MHz deflecting cavity and the 400 MHz crabbing cavity.

ELECTROMAGNETIC DESIGNS AND PROPERTIES

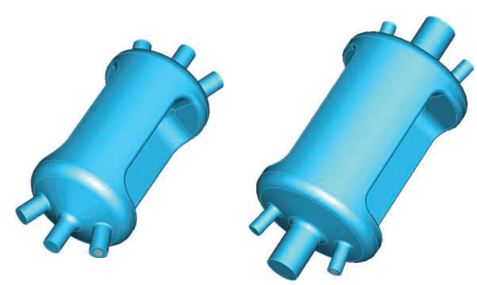


Figure 2: Final design geometries of 499 MHz deflecting cavity (left) and 400 MHz crabbing cavity (right)

The parallel-bar geometries for the 499 MHz deflecting cavity and the 400 MHz crabbing cavity are shown in Fig. 2. The geometry has a horizontal electric field component of the form of a cosine function and a sinusoidal form vertical magnetic field on axis. The longitudinal electric field is zero along the beam axis. The 499 MHz and the 400 MHz cavities are expected to deliver a transverse voltage of 5.6 MV and 10 MV per beam per side.

Four external ports have been added to maintain the symmetry and two of those will be used for power coupling and pick up. The beam and coupler port lengths are determined considering field decay and to reduce field enhancements at the flanges. The edges in the cavity and ports are rounded adequately considering the fabrication limitations and also to minimize the peak surface fields on those areas. The end caps of the cavity are designed with a slope to increase the efficiency in removing the chemicals during the chemical processing of the cavity surfaces.

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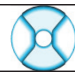
Table 1: Properties of the 499 MHz deflecting cavity and 400 MHz crabbing cavity designs.

Parameter			**Units**
Frequency of π mode	499.0	400.0	MHz
$\lambda/2$ of π mode	300.4	375.0	mm
Frequency of 0 mode	1036.1	887.0	MHz
Frequency of near neighbour mode	777.0	589.5	MHz
Cavity length	440.0	527.2	mm
Cavity diameter	241.2	339.9	mm
Bars length	260.0	350.0	mm
Bars inner height	50.0	80.0	mm
Angle	50.0	50.0	deg
Aperture diameter	40.0	84.0	mm
Deflecting voltage (V_T^*)	0.3	0.375	MV
Peak electric field (E_P^*)	2.86	3.9	MV/m
Peak magnetic field (B_P^*)	4.38	7.13	mT
B_P^* / E_P^*	1.53	1.83	mT/ (MV/m)
Energy content (U^*)	0.029	0.19	J
Geometrical factor	105.9	138.7	Ω
$[R/Q]_T$	982.5	287.2	Ω
$R_T R_S$	1.04×10^5	4.0×10^4	Ω^2
Field Non-Uniformity	At 10 mm	At 21 mm	
Offset in x	2.42	3.87	%
Offset in y	2.83	4.49	%

At $E_T^* = 1$ MV/m

The higher order modes (HOMs) spectrum shown in Fig. 3 has fundamental deflecting/crabbing mode as the lowest mode present in the geometry with the nearest mode widely separated at 1.5 times the fundamental mode frequency [3]. The parallel-bar cavity with trapezoidal shaped bars has wider mode separation in the HOM spectrum making this geometry very attractive in HOM damping, especially in high current applications.

The field non-uniformity is a measure of the field variation off the beam axis [2] where the percentage field variation in off x and y axes are shown in Table 1. The 499 MHz design with the 40 mm beam aperture has more uniform fields compared to 400 MHz crabbing cavity at an offset of half beam aperture radius. The inner bar height of parallel bars is important to achieve more uniform fields across the beam aperture, therefore is kept at an optimal height. However reducing the height is advantageous in reducing the peak fields in the cavity.

CAVITY DEVELOPEMENT AND ROOM TEMPERTURE MEASUREMENTS

The 499 MHz deflecting cavity is currently in the process of fabrication and the 400 MHz crabbing cavity is completely fabricated and is in preparation for rf testing. The two designs are fabricated using the material Nb following two different approaches [4, 5]. Prior to Nb the fabrication of parts were tested using Nb, Cu materials. The 499 MHz cavity is fabricated at Jefferson Lab in 6 parts, with separate end caps, center shell and center block carved with Nb ingot. The 400 MHz cavity is fabricated by Niowave Inc. with end caps and the center body formed in two pieces using a single forming die.

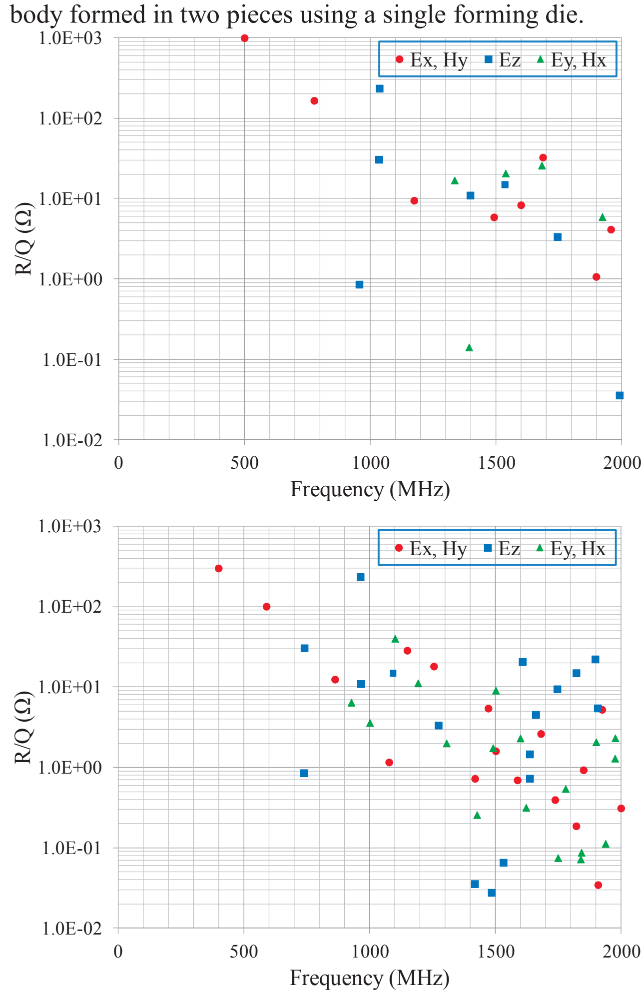


Figure 3: HOM spectrum for the 499 MHz deflecting cavity (top) and 400 MHz crabbing cavity (bottom).

The frequency is measured in the 499 MHz deflecting cavity by pressing parts together using a setup of fixtures and a vector network analyzer (VNA). Also the frequency spectrum is measured in the 400 MHz crabbing cavity at room temperature as shown in Fig. 4.

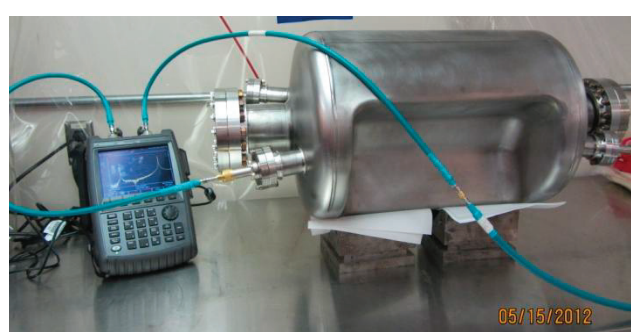


Figure 4: Setup for room temperature measurements for the 400 MHz crabbing cavity.

The frequency of the fundamental modes for the deflecting cavity and the crabbing cavity at room temperature is measured to be 500.8 MHz and 400.7 MHz respectively. The VNA measurements of the first two modes for the 400 MHz crabbing cavity are shown in Fig. 5, with a mode separation of 190 MHz. The HOM modes for the both the cavities up to 2 GHz have been measured and compared with the results from the EM simulations using CST Microwave Studio.

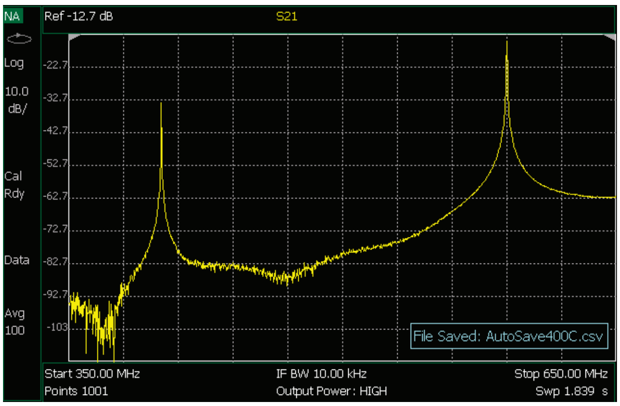


Figure 5: Fundamental deflecting/crabbing mode and next neighbour mode (589.5 MHz) for the 400 MHz crabbing cavity.

NEXT GENERATION OF PARALLEL-BAR CAVITY DESIGN

The 400 MHz "proof of principle" crabbing cavity is comparatively larger in transverse dimensions in meeting the LHC crabbing cavity specifications. Therefore a compact square cavity is designed as shown in Fig. 8 with fixed transverse dimensions of 295 mm while the design frequency is achieved by appropriately curving edges of the cavity. However this design has higher off-axis field variations, therefore the design is altered by curving the inner wall of the parallel bar to reduce the field non-uniformity as shown in Fig. 6. The properties for both designs are shown in Table 2. The parallel-bar design with curved inner walls has higher surface fields but very low field non-uniformity.

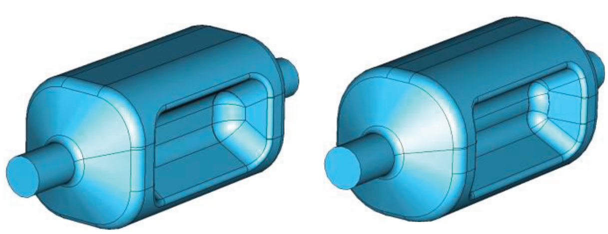


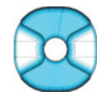
Figure 6: 400 MHz crabbing cavity with flat (left) and curved (right) inner bar surface.

CONCLUSION

The first prototype of the 499 MHz deflecting cavity is currently under fabrication with all the parts machined. The parts will be electropolished for chemical surface treatment following a light buffered chemical polishing (BCP) after the final welding. The fabricated 400 MHz "proof of principle" cavity will be chemical etched with bulk BCP treatment at the BCP cabinet at Jefferson Lab. The cavities will be baked at 600^{0}C with an in-situ bake at ~120^{0}C. Both the cavities is planned to be tested at 2K and 4K using a variable coupler assembly.

The 400 MHz "squarish" crabbing cavity is designed to meet the current design specifications of the proposed LHC luminosity upgrade. The design will be finalized considering the updated specifications on peak surface fields and field non-uniformity.

Table 2: Properties of the 400 MHz crabbing cavity designs with flat and curved inner bar surfaces.

Parameter			**Units**
Frequency of π mode	400.0	400.0	MHz
λ/2 of π mode	375.0	375.0	mm
Frequency of 0 mode	727.4	758.2	MHz
Frequency of near neighbour mode	593.2	581.8	MHz
Cavity length	597.2	597.2	mm
Cavity diameter	295.0	295.0	mm
Bars length	350.3	350.3	mm
Bars inner height	85.0	85.0	mm
Angle	30.0	30.0	deg
Aperture diameter	84.0	84.0	mm
Deflecting voltage (V_T^*)	0.375	0.375	MV
Peak electric field (E_P^*)	3.86	4.23	MV/m
Peak magnetic field (B_P^*)	6.9	7.69	mT
B_P^* / E_P^*	1.79	1.82	mT/ (MV/m)
Energy content (U^*)	0.18	0.17	J
Geometrical factor	115.0	108.5	Ω
$[R/Q]_T$	315.7	336.4	Ω
$R_T R_S$	3.6×10^4	3.7×10^4	Ω^2
Field Non-Uniformity			
At 15 mm offset in x	2.91	0.3	%
At 15 mm offset in y	3.04	1.1	%

At $E_T^* = 1$ MV/m

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