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Jean R. Delayen
Old Dominion University, jdelayen@odu.edu

Subashini De Silva
Old Dominion University, pdesilva@odu.edu

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DESIGN OF SUPERCONDUCTING PARALLEL-BAR DEFLECTING/CRABBING CAVITIES*

J.R. Delayen[1,2#], S.U. De Silva[1,2],
[1]Center for Accelerator Science, Old Dominion University, Norfolk, VA 23529, USA.
[2]Thomas Jefferson National Accelerator Facility, Newport News, VA 23606, USA.

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. We present an analysis of several designs of parallel-bar cavities and their electromagnetic properties.

INTRODUCTION

The two major applications of the superconducting parallel-bar cavity [1] are the 499 MHz deflecting cavity for the Jefferson Lab 12 GeV upgrade and the 400 MHz crabbing cavity for the proposed LHC luminosity upgrade. The parallel-bar designs for the above two applications are being optimized and is in the process of fabricating Nb prototypes. The parallel-bar geometry is also being considered for the 750 MHz crab cavity for the medium energy electron ion collider (MEIC) at Jefferson Lab and as the deflecting cavity for Project-X operating at 365.625 MHz.

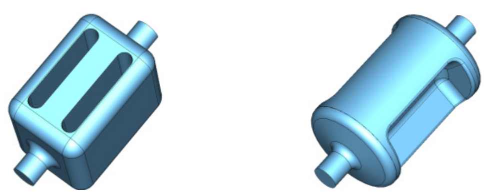

Figure 1: Rectangular shaped (left) and cylindrical shaped parallel-bar geometries.

The initial rectangualr shaped parallel-bar geometry with straight race-track shaped bars has higher peak surface magneitc fields. This geometry doesn't allow to have balanced peak surfac fields therfore have been improved into the geometry with cylidrical outer condcutor and trapezoidal shaped bars as shown in Fig. 1. This final geometry is proven to have improved properties [2, 3] such as low and well balanced peak surface electric and magnetic fields with higher transverse [*R*/*Q*] and higher geometrical factor (*G*). The key advantage of the trapezoidal shaped bars is that it allows optimizing the geometry to achieve the balanced surface fields based on the design requirements of the application, by varying the design parameters of angle and inner bar height as shown in Fig. 2. Increasing the angle increases the peak surface magnetic field while increasing the inner bar height reduces the peak surface electric field. Therefore optimizing these two parameters allows having the best peak surface balancing ratio required for each application to achieve the maximum deflection for given design frequency, beam aperture and required operating transverse voltage.

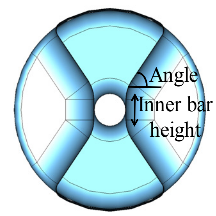

Figure 2: Optimized design parameters of the bars in the parallel-bar geometry.

The parallel-bar geometry also eliminates the wider flat surfaces on previous designs reducing surface deformation due to radiation pressure and pressure fluctuations due to liquid He. The shape of the bars connecting to the cylindrical outer conductor adds more rigidity to the geometry.

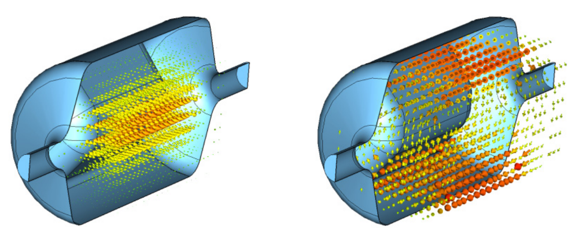

Figure 3: Electric field profile (left) and magnetic field profile (right) of the parallel-bar cavity.

The electric and magnetic field profiles are shown in Fig. 3. In the parallel-bar geometry the beam is deflected by the transverse electric field between the bars. The transverse electric field and magnetic field at 1J of stored energy is shown in Fig. 4. There is no longitudinal electric field along the beam line. The vertical magnetic field opposes the net deflection; however the resultant contribution from this component is small.

The parallel-bar geometry has uniform transverse electric field along the beam line. The length of the cavity and the bar length are optimized to achieve a higher net deflection, by increasing the effective length of deflection. The optimized bar length is closer to half wave length as opposed to the cavity length being of half wave length.

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#delayen@jlab.org

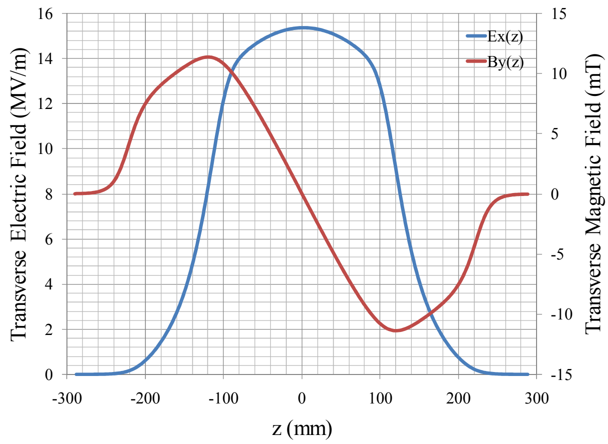

Figure 4: Transverse electric field and magnetic field along the beam line.

PARALLEL-BAR CAVITY APPLICATIONS

499 MHz Deflecting Cavity

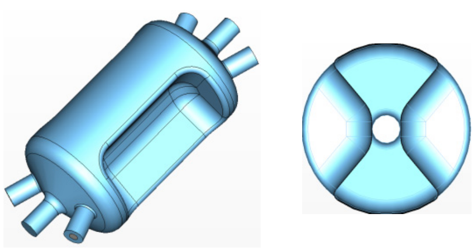

Figure 5: 499 MHz deflecting cavity (left) and the cross section (right).

The 499 MHz parallel-bar cavity shown in Fig.5 is one of the options proposed as the rf separator for the Jefferson Lab 12 GeV upgrade. The other option is to use 8 of the existing normal conducting cavities in operating for the 6 GeV beam. The rf separator is required to deliver the 11 GeV beam in to the 3 experimental halls simultaneously hence need a total deflecting voltage of 5.6 MV. The beam current for Hall and C is 85 µA and 1 µA for Hall B.

The optimized cavity needs to be operated at peak surface fields of E_P=27 MV/m and B_P=42 mT with a field balancing ratio of B_P/E_P=1.55 mT/(MV/m) to deliver a 2.8 MV transverse voltage per cavity. The higher [R/Q] and geometrical factor gives a higher R_TR_S (R_T – Transverse Shunt Impedance and R_S – Surface Resistance) reducing the power dissipation through the walls. The final properties of the deflecting cavity are shown in Table 1.

400 MHz Crabbing Cavity

The 400 MHz parallel-bar crabbing cavity for the proposed LHC luminosity upgrade is required to crab the beam in both horizontal and vertical direction at separate interaction points (IPs) in ATLAS and CMS experiments in the LHC ring. This sets the major dimensional constraint in the 400 MHz crabbing cavity limiting the diameter to be less than 300 mm. The design of the 400 MHz prototype crabbing cavity is shown in Fig. 6; the final design will have an outer shell closer to a square shape in order to meet the size requirements.

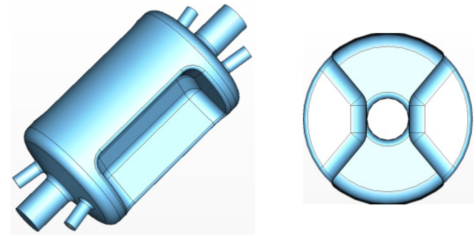

Figure 6: 400 MHz crabbing cavity (left) and the cross section (right).

The larger beam aperture gives rise to smaller net deflection with higher surface fields. The optimized design has operating peak surface fields of E_P=36 MV/m and B_P=65 mT with a field balancing ratio of B_P/E_P=1.83 mT/(MV/m). This ratio allows reducing the tolerable peak the surface magnetic field at 3.4 MV of deflecting voltage per cavity. The properties of the final 400 MHz design are shown in Table 1.

The mechanical analysis is being carried out for the above designs [4] to determine the need of additional reinforcements for stiffening the cavity. The 499 MHz design will be fabricated at Jefferson Lab and the 400 MHz design will be fabricated with the collaboration with Niowave Inc.

Other Deflecting/Crabbing Applications

The preliminary design analysis of the 750 MHz crabbing cavity for the future MEIC at Jefferson Lab and the 365.625 MHz deflecting cavity for the Project-X have been performed and the current design properties shown in Table 1. The design geometries are shown in Fig. 7.

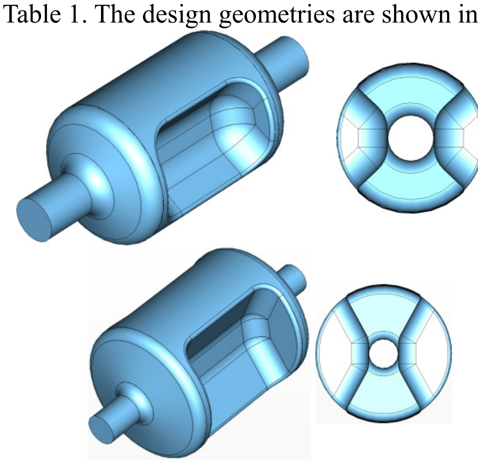

Figure 7: 750 MHz crabbing cavity (top) and 365.625 MHz deflecting cavity (bottom).

The 750 MHz crab cavity is required to crab the 60 GeV proton beam to enable head on collision with the 12 GeV electron beam with a transverse voltage of 1.35 MV

Table 1: Properties of the 499 MHz, 365.6 MHz deflecting cavity designs and 400 MHz, 750 MHz crabbing cavity designs.

Parameter	499 MHz	400 MHz	750 MHz	365.6 MHz	Units
Frequency of π mode	499.0	400.0	750.0	365.625	MHz
λ/2 of π mode	300.4	375.0	199.9	410.0	mm
Frequency of 0 mode	1033.3	729.4	1314.4	659.7	MHz
Frequency of near neighbour mode	776.6	589.5	1143.1	571.9	MHz
Cavity length	440.0	527.2	300.0	530.0	mm
Cavity diameter	242.2	339.9	193.0	388.4	mm
Bars length	260.0	350.3	185.0	350.0	mm
Bars inner height	50.0	80.0	57.5	85.0	mm
Angle	50.0	50.0	36.2	55.0	deg
Aperture diameter	40.0	84.0	60.0	84.0	mm
Deflecting voltage (V_T^*)	0.3	0.375	0.2	0.41	MV
Peak electric field (E_P^*)	2.85	3.9	4.95	3.61	MV/m
Peak magnetic field (B_P^*)	4.43	7.13	8.74	6.41	mT
B_P^* / E_P^*	1.55	1.83	1.77	1.77	mT/(MV/m)
Energy content (U^*)	0.029	0.19	0.056	0.19	J
Geometrical factor	106.0	138.7	136.9	115.9	Ω
$[R/Q]_T$	977.4	287.2	152.9	378.5	Ω
$R_T R_S$	1.04×10^5	4.0×10^4	2.1×10^4	4.4×10^4	Ω^2

At $E_T^* = 1$ MV/m

This design has a higher ratio of beam aperture to wavelength and as a result has higher peak surface fields.

The Project-X 365.625 MHz deflecting cavity is required to separate the 3 GeV proton beam into 3 beams. The design has very attractive properties due to the low frequency of the application. A 3.4 MV transverse voltage per cavity can be achieved with peak surface fields of E_P=30 MV/m and B_P=54 mT, which requires 3 deflecting cavities to deliver the full deflection of 10 MV.

FUNDAMENTAL POWER COUPLER DESIGN

The parallel-bar geometry has the capability of coupling to the fundamental mode using both electric and magnetic coupling. The magnetic field at top and bottom of the cavity gives strong coupling to the fundamental mode, however gives rise to field enhancement. The off-axis longitudinal electric field near the end plates gives adequate coupling to the fundamental mode in the parallel-bar cavity.

Table 2: Fundamental power coupler parameters for 499 MHz and 400 MHz parallel-bar cavity designs.

	499 MHz	400 MHz	Units
Diameter of inner rod	17.5	15.6	mm
Diameter of outer conductor	40.2	36.2	mm
External Q	6.8×10^6	3.3×10^6	

A 50 Ω coaxial coupler is used to couple to the electric field with dimensions given in Table 2. A variable coupler will be used to achieve the required coupling in testing the cavity prototypes. The 400 MHz cavity doesn't require beam loading. Four coupler ports are added to the cavity geometry to eliminate the asymmetry and to reduce the longitudinal electric field along the beam line.

CONCLUSION

The parallel-bar cavity design allows maximizing the deflecting voltage on each design specific for each application, by optimizing the trapezoidal shaped bars to have low and well balanced peak surface fields. The higher geometric factor increases the $R_T R_S$ reducing the power losses through the walls. There are no lower-order modes present in the parallel-bar geometry and the wider frequency separation of the fundamental mode and next near neighbor mode make this design attractive in higher order mode damping in high current applications. The 499 MHz and 400 MHz are being optimized to meet the design requirements. Prototype fabrication of these designs are ongoing.

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