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Pathways for a compact double-quarter wave cavity with low peak surface fields and large deflecting kick

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DISCLAIMER

PATHWAYS FOR A COMPACT DOUBLE-QUARTER WAVE CAVITY WITH LOW PEAK SURFACE FIELDS AND LARGE DEFLECTING KICK*

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Abstract

This paper describes the parameter choices necessary to obtain a compact Double Quarter Wave (DQW) cavity with low peak surface fields – electric and magnetic – and large deflecting kick. The work is motivated by the space limitations and demanding crabbing voltage required for the crabbing system of the Electron-Ion Collider (EIC) and focuses on the optimization of the 197 MHz crab cavities for the EIC's hadron ring. For a crabbing voltage of 11.5 MV, the optimized cavity is less than one meter long, showing a maximum peak surface magnetic field of 70 mT and a maximum peak surface electric field of 45 MV/m.

INTRODUCTION

The large crossing angle of the EIC and the dense lattice of its interaction regions motivates the development of a compact crab cavity design that provides a large deflecting kick with reasonable peak surface field values that do not compromise operation. The goal is to keep the maximum peak surface magnetic field below 80 mT and the maximum peak surface electric field below 50 MV/m.

This study focuses on the optimization of the 197 MHz crab cavity for the hadron beam crabbing. The cavity will need to provide a horizontal crabbing kick of 11.5 MV [1]. The aperture of the cavity is fixed to 100 mm. The optimization of the cavity design is performed with the 3D electromagnetic solver of the CST Studio Suite [2]. Fig. 1 shows the main parts of a DQW cavity. The design will use flat outer conductor walls in contrast to the HL-LHC DQW crab cavity design which incorporated a "waist" to avoid the adjacent pipe hosting the second beam.

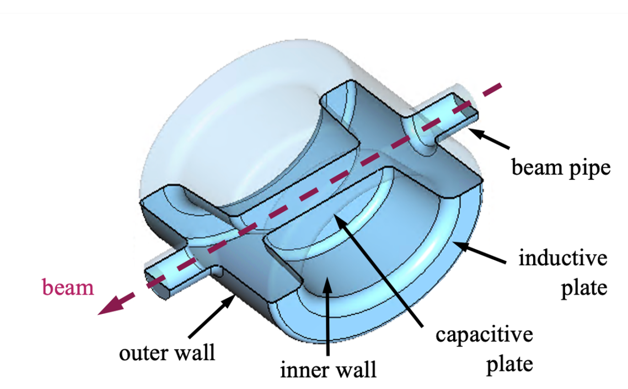

Figure 1: Main DQW cavity parts.

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PATHWAY TO LOW B_{pk} / $V_\perp$

A low maximum peak surface magnetic field (B_{pk}) over deflecting voltage ratio ($V_\perp$) can be found by means of adjusting:

- The inner conductor's wall slope (θ_{IC}) – see Fig. 2. This parameter, together with the blending radius applied to the edge where the inner conductor wall meets the inductive plate (r_{IC}), helps smoothing the contour of the region where the magnetic field is the highest.
- The ellipticity (e). The longer the cavity in the longitudinal direction, and in turn, its capacitive plates, the larger the kick received by the bunch. However, the ellipticity cannot be indefinitely increased because it leads to higher surface current density in the regions near to the ellipse's foci.

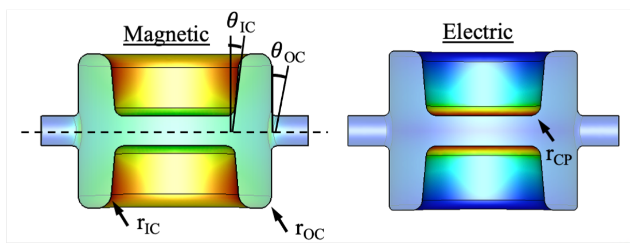

Figure 2: Stored energy distribution – magnetic and electric – for the fundamental, deflecting mode of a DQW cavity.

A rounded dome helps reducing further the $B_{pk}/V_\perp$ in comparison to the classic, flat dome, as shown in Fig. 4. The impact of the outer wall slope (θ_{IC}) on $B_{pk}/V_\perp$ was also studied, but no benefit was found.

PATHWAY TO LOW E_{pk} / $V_\perp$

A low maximum peak surface electric field (E_{pk}) over deflecting voltage ratio ($V_\perp$) can be found thanks to adjusting the blending radius applied to the edge of the capacitive plates (r_{CP}). The value of r_{CP} has no significant impact on the geometric shunt impedance of the fundamental, deflecting mode ($R_\perp/Q$), i.e. the efficiency to provide the deflecting kick is maintained despite modifying the capacitive plate. Nor there is an impact on $B_{pk}/V_\perp$ as expected in first-order approximation. Nonetheless, r_{CP} cannot be increased indefinitely for the elliptical profile – beyond a certain r_{CP}, the modeling software is unable to blend the sharp curvature at the summits of the major axis. The maximum r_{CP} that can be implemented thus depends on the ellipticity, e.g. for r_M/r_m of 1.5, the maximum r_{CP} is 40 mm, where r_M is the major axis of the ellipse and r_m is the minor axis.

OVATED PROFILE TO FURTHER REDUCE $B_{pk}/V_{\perp}$ AND $E_{pk}/V_{\perp}$

The solution to further reduce both $B_{pk}/V_{\perp}$ and $E_{pk}/V_{\perp}$ is to employ an ovated profile instead of an elliptical one. This is the main novelty introduced after the DQW cavity concept developed for the high luminosity Large Hadron Collider (HL-LHC). The ovated profile is obtained by intersecting a spindle torus with a plane perpendicular to its axis of revolution. The resulting curve is a Cassini oval [3,4], which presents smoother curvature at the regions close to the foci than an ellipse or a racetrack with the same width and length as illustrated in Fig. 3.

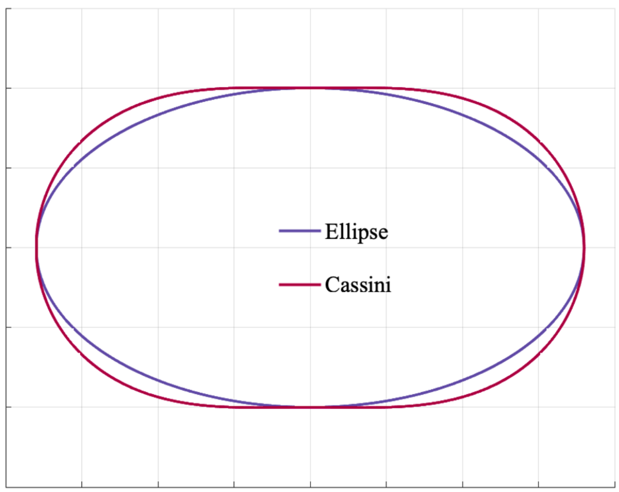

Figure 3: Comparison between ellipse and Cassini oval of equal width and length (r_m = 1; r_M = 1.5).

RESULTS AND CONCLUSIONS

Figures 4 and 5 show the dependence of $B_{pk}/V_{\perp}$ and $E_{pk}/V_{\perp}$ on the ellipticity of the cavity and the blending radius of the capacitive plates for DQW cavities with elliptical and ovated profiles. For the same r_{CP} value, the ovated profile provides lower $B_{pk}/V_{\perp}$ and $E_{pk}/V_{\perp}$ than the elliptical profile. The ovated profile also allows larger r_{CP} than the elliptical. As a result, the $B_{pk}/V_{\perp}$ and $E_{pk}/V_{\perp}$ are lower than for any other DQW geometries inspected.

Table 1 lists the main geometric parameters and electromagnetic quantities for an optimized DQW cavity with ovated profile. This compact cavity shows remarkable values for $V_{\perp}$ / E_{pk} / L = 0.33 and $V_{\perp}$ / B_{pk} / L = 0.21 MV/mT/m, being L the cavity length along the beam axis. The cavity length, 0.785 m, is comparable to half the wavelength of the fundamental, crabbing mode, 0.761 m. For a crabbing voltage of 11.5 MV, the cavity features reasonable maximum peak surface fields of 70 mT and 45 MV/m.

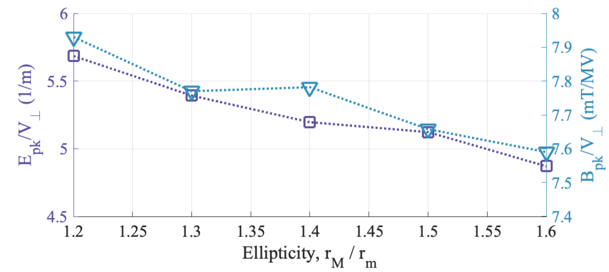

Figure 4: Maximum peak surface fields over deflecting voltage dependence on ellipticity for DQW cavities with elliptical profiles (r_{CP} = 30 mm).

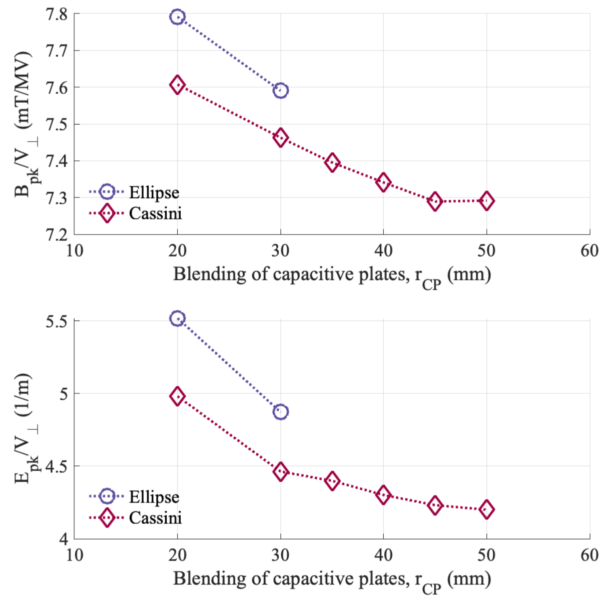

Figure 5: Maximum peak surface fields over deflecting voltage dependence on blending radius of capacitive plates for DQW cavities with elliptical and ovated profiles with equal width and length (r_M/r_m = 1.6).

REFERENCES

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[4] K. Gibson, "The ovals of Cassini", May 2007: https://mse.redwoods.edu/darnold/math50c/CalcProj/sp07/ken/CalcPpr.pdf

Table 1: Geometric and electromagnetic properties for the fundamental, deflecting mode of the optimized DQW with ovated profile

Geometric		
Aperture	100	mm
Outer conductor diameter, OCD	500	mm
Inner conductor diameter, ICD	250	mm
Inductor length, IL	242	mm
Inner wall angle, θ_{IC}	10	deg
Ellipticity, r_M / r_m	1.6	
Blending of capacitive plate, r_{CP}	50	mm
Blending of outer conductor, r_{IC}	15	mm
Blending of inner conductor, r_{OC}	35	mm
Height (x direction)	584	mm
Width (y direction)	453	mm
Length (z direction, w/o beam pipes)	785	mm
Electromagnetic		
Frequency, f	197	MHz
Geometric shunt impedance, $R_\perp/Q$	1160	Ohm
Geometric factor, G	68	Ohm
Ratio $B_{pk}/V_\perp$	6.0	mT/MV
Ratio $E_{pk}/V_\perp$	3.9	1/m

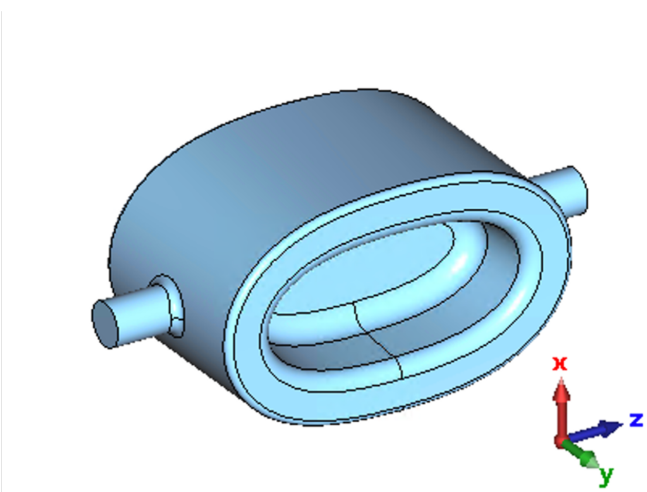

Figure 6: Optimized DQW cavity with ovated profile for reduced $B_{pk}/V_\perp$ and $E_{pk}/V_\perp$. The fundamental mode of the cavity provides a deflecting kick in the y direction.