# DESIGN OPTIMIZATION OF SUPERCONDUCTING PARALLEL-BAR CAVITIES*

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## ABSTRACT

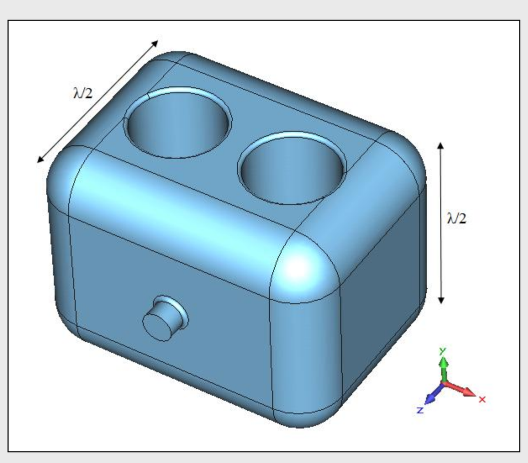
***The parallel-bar structure is a new superconducting geometry whose features and properties may have significant advantages over conventional superconducting deflecting and crabbing cavities for a number of applications. Jefferson Lab is in need for a 499 MHz, 11 GeV rf separator as part of its 12 GeV upgrade program. We report on design optimization studies performed to-date for this and other applications.***

## INTRODUCTION

The parallel-bar structure [1,2] is designed for both deflecting and crabbing of particle bunches. It consists of two cylindrical parallel bars of λ/2 length, perpendicular to the beam line passing through the bars. The parallel bars operate in TEM mode, generating two fundamental modes.

- Accelerating mode (0 mode) – parallel bars operate in phase with a voltage of the same sign
- Deflecting mode (π mode) – parallel bars oscillate in opposite phase with a voltage of opposite sign, producing a transverse voltage.

Deflecting Mode – Operates with the **lowest** frequency. The voltage is maximum between the bars containing the beam aperture generating the maximum deflection. The magnetic field is zero in the mid plane, and is maximum on the top and bottom surfaces. The electric field is zero on those surfaces and maximum in the mid plane; producing a deflection along the beam aperture only due to the electric field.




## PARAMETERS FOR DESIGN OPTIMIZATION

Main objective – To obtain the maximum deflecting voltage between the parallel bars, with lowest peak surface fields. The effective deflecting length in which the particle passes through is also equally essential in supplying a higher deflection to the particle bunch.

In a deflecting cavity structure the center of the bunch receives the deflection and in a crabbing structure the head and tail of the beam bunch receive deflections in opposite direction.

Transverse voltage ($V_T$) seen by a particle on crest,

$$V_T = \int_{-\infty}^{+\infty} E_X(z) \cos\left(\frac{\omega z}{c}\right) dz$$

$E_X(z)$ – Transverse component of the longitudinal electric field

$\omega$ – Frequency of the structure

The effective length of the structure along the beam line for a particle travelling in velocity of light is λ/2.

Transverse electric field

$$E_T = \frac{V_T}{\lambda/2}$$

Transverse shunt impedance

$$R_T = \frac{V_T^2}{P}$$

Geometrical factor

$$G = QR_S$$

Transverse [R/Q]

$$\left[\frac{R}{Q}\right]_T = \frac{V_T^2}{\omega U}$$

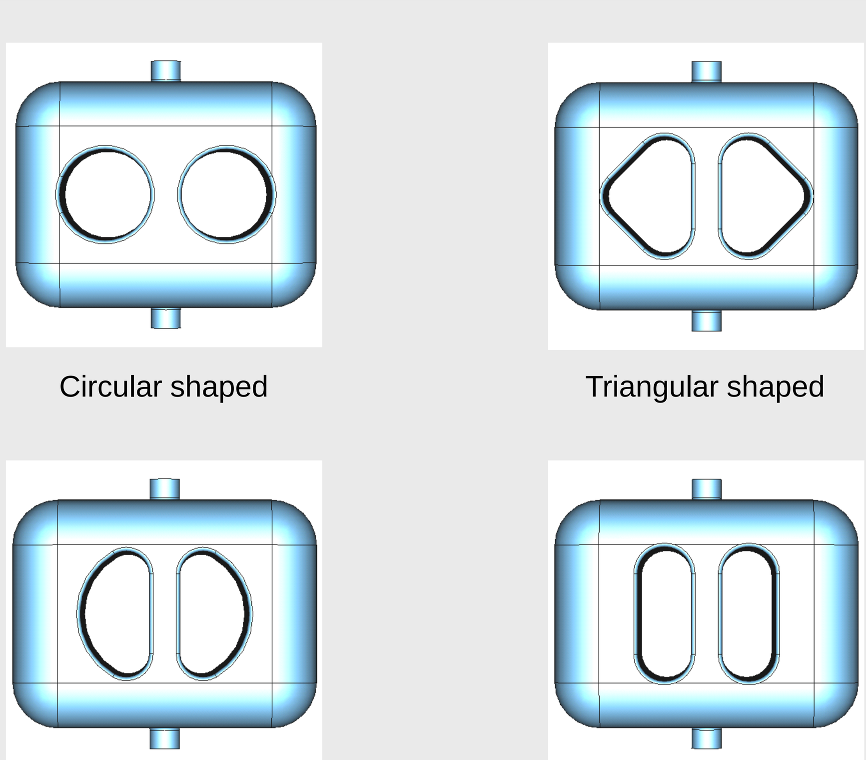
$\lambda$ – Wave length

$Q$ – Quality factor

$P$ – Power loss through walls

$R_S$ – Surface Resistance

## PARALLEL-BAR STRUCTURE DESIGNS



Circular shaped | Triangular shaped | Half circular shaped | Race track shaped

- Initial design length and height = 375 mm, width = 400 mm
- Beam aperture diameter = 40 mm
- In each structure the parallel-bars are appropriately curved to reduce the field concentration near the edges

CEBAF currently uses the normal conducting rf separator cavity [3] operating at 6 GeV. Proposed cavity design is expected to pass the beam to the 3 experimental halls at the maximum energy.

The design requirement for the CEBAF upgrade is to provide a vertical deflection of 525 μrad for a particle on crest with energy 11.023 GeV. Then the electron beams for the experimental halls (Hall A and Hall C) will receive a deflection of 455 μrad at 30° off crest.

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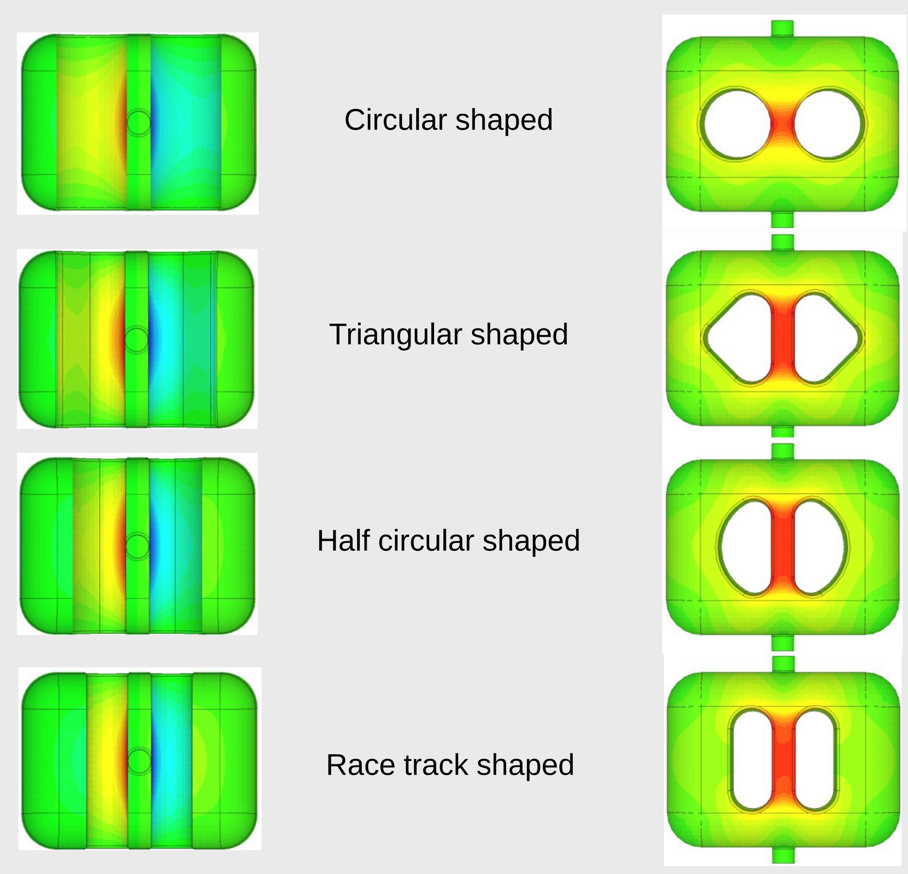
## SIMULATION RESULTS

**Peak surface electric and magnetic field values for the four structures**

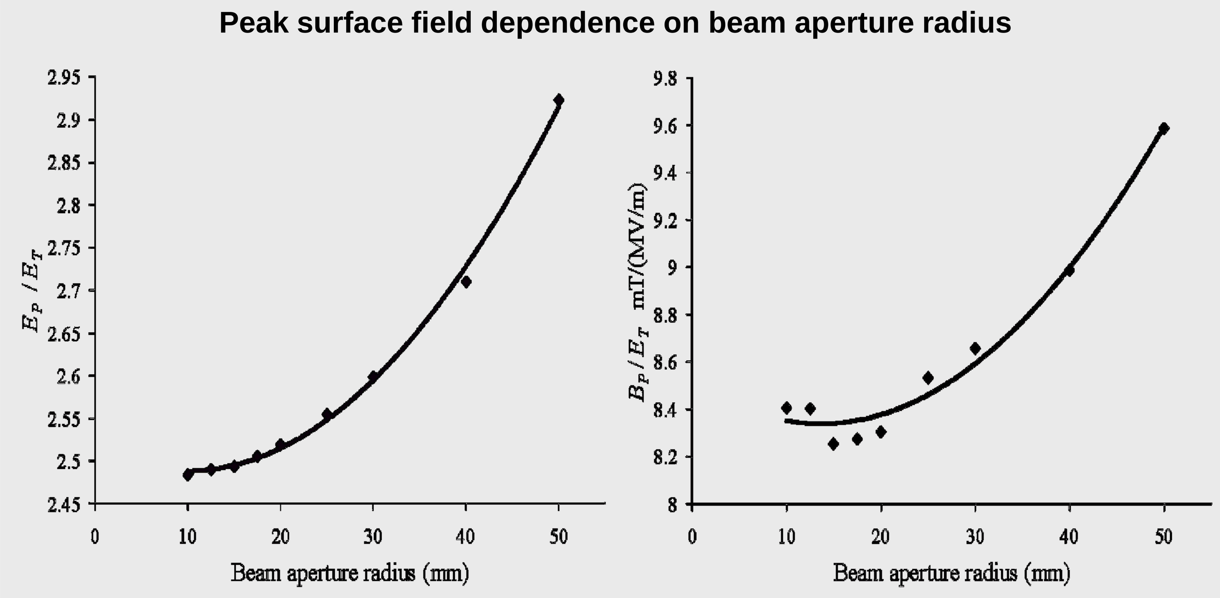
| Design structure | $E_P / E_T^*$ (MV/m) | $B_P / E_T^*$ (mT) |
|---|---|---|
| Circular shaped | 3.45 | 8.86 |
| Triangular shaped | 2.47 | 6.60 |
| Half circular shaped | 2.30 | 6.15 |
| Race track shaped | 2.28 | 5.94 |

At $E_T^*$ = 1 MV/m

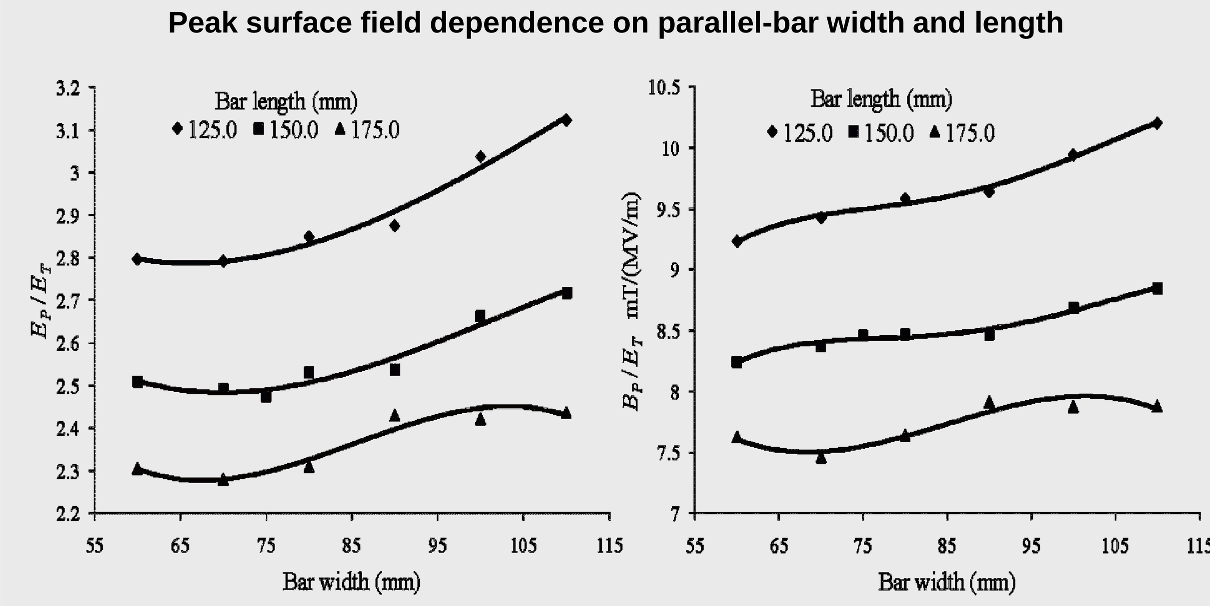
**Surface electric field between the bars (left) and surface magnetic field on the top surface (right)**



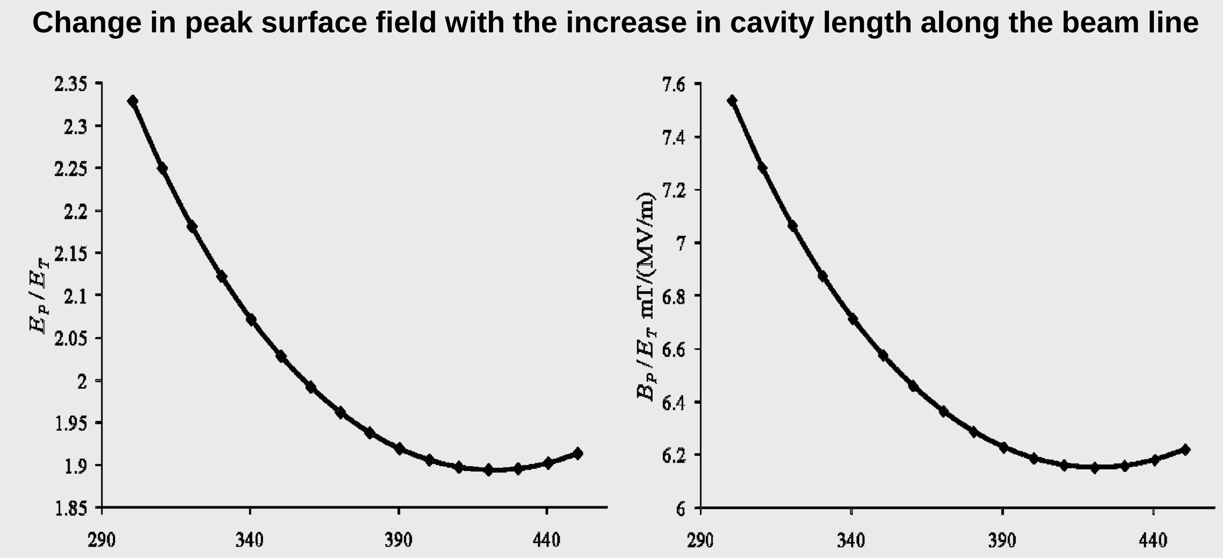

**Peak surface field dependence on beam aperture radius**




**Peak surface field dependence on parallel-bar width and length**




**Change in peak surface field with the increase in cavity length along the beam line**




Different parallel-bar structures were analyzed to obtain a uniform field between the bars.

### *Results of the deflecting cavity structure*

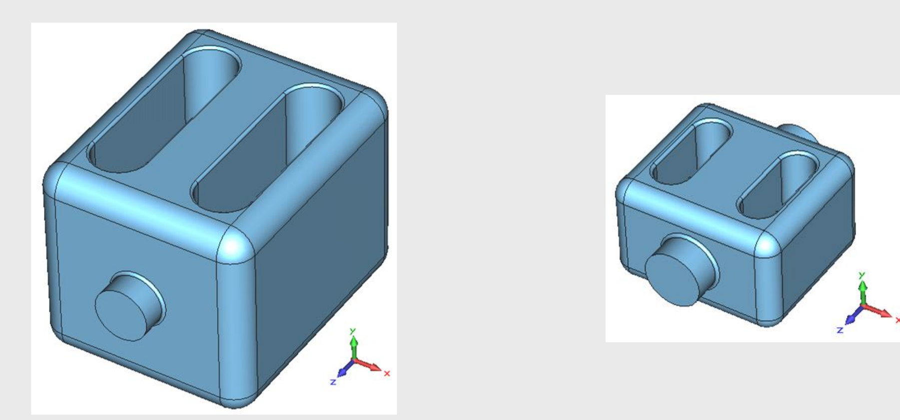
| Parameter | Race track structure | CEBAF | Units |
|---|---|---|---|
| Freq. of π mode | 499 | 499 | MHz |
| λ/2 of π mode | 300.4 | 300.4 | mm |
| Freq. of 0 mode | 521.9 | ~537 | MHz |
| Cavity length | 420.4 | ~300 | mm |
| Cavity width | 320 | 292 | mm |
| Bars height | 305.5 | 20 | mm |
| Bars width | 70 | 20 | mm |
| Bars length | 295 | 135 | mm |
| Aperture diameter | 40 | 15 | mm |
| Deflecting voltage ($V_T$*) | 0.3 | 0.3 | MV |
| Peak electric field ($E_P$*) | 1.9 | 3.39 | MV/m |
| Peak magnetic field ($H_P$*) | 4.9 | 8.87 | mT |
| Energy content ($U$*) | 0.028 | 0.0012 | J |
| Geometrical factor | 69.4 | 34.9 | Ω |
| $[R/Q]_T$ | 1045.3 | 24921 | Ω |

At $E_T^*$ = 1 MV/m

- Comparison of properties with the existing normal conducting rf separator cavity
- Low surface fields were achieved for a higher deflection with high $[R/Q]_T$
- A mode separation of 20 MHz is achieved between the deflecting mode and the fundamental mode

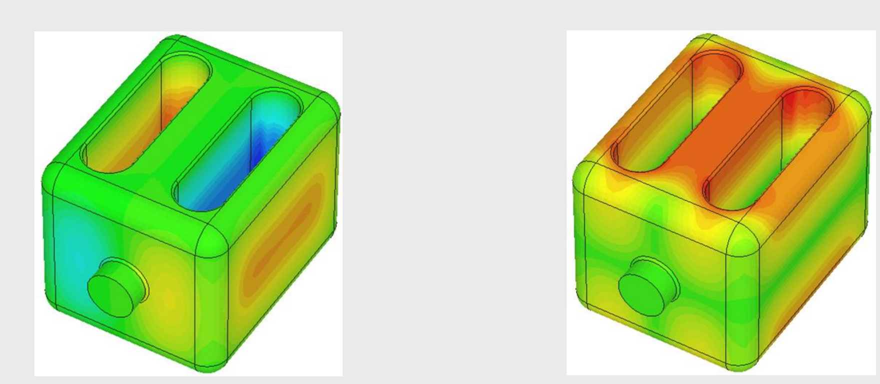
### *Crabbing cavity structures*

In considering other applications two crabbing cavity structures of frequencies 400 MHz and 800 MHz for possible use in an LHC upgrade were analyzed.

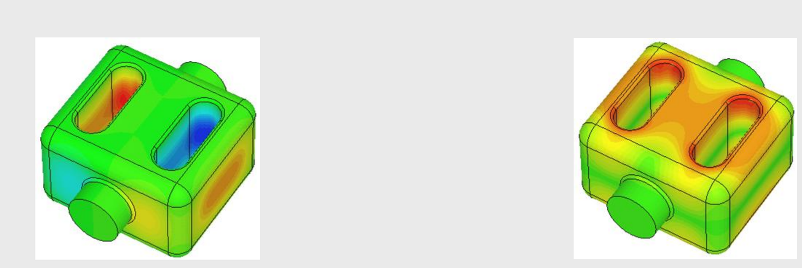


400 MHz crabbing cavity | 800 MHz crabbing cavity

**Surface electric field (left) and magnetic field (right) of 400 MHz crabbing cavity**



**Surface electric field (left) and magnetic field (right) of 800 MHz crabbing cavity**



### *Results of crabbing cavity structures*

| Parameter | 400 MHz cavity | 800 MHz cavity | Units |
|---|---|---|---|
| Freq. of π mode | 400 | 800 | MHz |
| λ/2 of π mode | 374.7 | 187.4 | mm |
| Freq. of 0 mode | 407.1 | 815.3 | MHz |
| Cavity length | 494.7 | 267.4 | mm |
| Cavity width | 400 | 300 | mm |
| Bars height | 382.2 | 191.8 | mm |
| Bars width | 100 | 60 | mm |
| Bars length | 370 | 170 | mm |
| Aperture diameter | 100 | 100 | mm |
| Deflecting voltage ($V_T$*) | 0.375 | 0.187 | MV |
| Peak electric field ($E_P$*) | 2.16 | 2.79 | MV/m |
| Peak magnetic field ($H_P$*) | 7.05 | 9.78 | mT |
| Energy content | 0.175 | 0.062 | J |
| Geometrical factor | 81.37 | 112.3 | Ω |
| $[R/Q]_T$ | 319.13 | 113.55 | Ω |
| $R_T R_S$ | $2.6\times10^4$ | $1.3\times10^4$ | $\Omega^2$ |

At $E_T^*$ = 1 MV/m

## CONCLUSION

The parallel-bar structure has been optimized for the applications of CEBAF upgrade and LHC. The optimized design is the structure with race track shaped parallel bars. This design allows high deflecting voltage for low surface fields with high shunt impedance. The optimized designs support low frequencies of operation due to its compact size. One advantage of this design, compared to the conventional superconducting deflecting and crabbing structures is that the deflecting mode has the lowest frequency; hence HOM damping requires only damping of all the higher order frequencies. Further analysis requires the study of the effects of multipacting and HOM damping of the parallel-bar structure.

## REFERENCES

[1] J.R. Delayen and H. Wang, “A New TEM-Type Deflecting and Crabbing RF Structure,” LINAC’08, Vancouver, BC, Canada.

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[3] C.W. Leeman and C.G. Yao, “A Highly Effective Deflecting Structure,” LINAC’90, Albuquerque, New Mexico, p. 232.

[4] J.R. Delayen, M. Spata and H. Wang, “Options for an 11 GeV RF Beam Separator for the Jefferson Lab CEBAF Upgrade,” PAC’09, Vancouver, BC, Canada.