2011

Fundamental and HOM Coupler Design of the Superconducting Parallel-Bar Cavities

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

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

Original Publication Citation

De Silva, S. U., & Delayen, J. R. (2011). *Fundamental and HOM Coupler design of the superconducting parallel-bar cavities* [Conference Paper]. 2011 Particle Accelerator Conference, New York, New York. https://accelconf.web.cern.ch/pac2011/papers/tup097.pdf

FUNDAMENTAL AND HOM COUPLER DESIGN OF THE SUPERCONDUCTING PARALLEL-BAR CAVITY*

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

Abstract

The superconducting parallel-bar cavity [1] is currently being considered as a deflecting system for the Jefferson Lab 12 GeV upgrade and as a crabbing cavity for a possible LHC luminosity upgrade. Currently the designs are optimized to achieve lower surface fields within the dimensional constraints for the above applications. A detailed analysis of the fundamental input power coupler design for the parallel-bar cavity is performed considering beam loading and the effects of microphonics. For higher beam loading the damping of the HOMs is vital to reduce beam instabilities generated due to the wake fields. An analysis of threshold impedances for each application and impedances of the modes that requires damping are presented in this paper with the design of HOM couplers.

INTRODUCTION

The superconducting parallel-bar cavity is currently being considered as a deflecting cavity for the Jefferson Lab 12GeV upgrade, and as a crab cavity for the proposed LHC Luminosity upgrade. It is also being proposed as the rf deflector for the Project-X and as one of the options for ELIC crab cavity. The geometries for some of these applications are shown in Fig. 1.

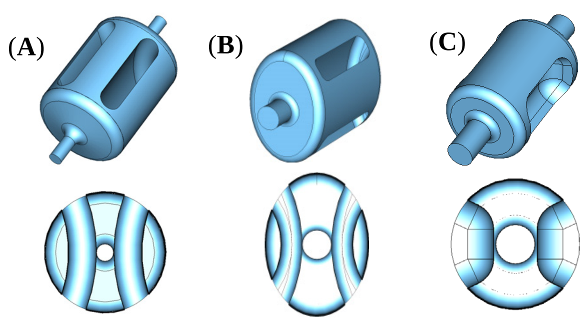

Figure 1: Parallel-bar cavity designs. (A) 499 MHz cylindrical shaped design with curved bars, (B) 400 MHz elliptical shaped design with curved bars and (C) 750 MHz cylindrical shaped design with bars merged on to the walls (top) and vertical cross section of each design (bottom).

These geometries have improved properties over the rectangular shaped parallel bar cavity [2] that was proposed initially for the above mentioned applications. The cylindrical and elliptical shaped geometries have balanced surface fields that support a higher deflecting voltage. Also wider mode separation makes these designs attractive in damping higher order modes (HOM).

The elliptically parallel-bar cavity is optimized to meet the requirements and dimensional constraints for the proposed LHC luminosity upgrade. The two parallel-beam lines with a separation of 194 mm between the axes and beam aperture radii of 42mm set the key constraints in the horizontal dimension. Therefore the proposed elliptical shape is adopted, with a cavity width of 300 mm over a cylindrical shaped cavity. This increases the surface fields in the design. However the peak surface magnetic fields are comparatively low compared to that of a rectangular shaped design due to the wider separation of the parallel bars at the surface connecting to the outer conductor.

The fundamental input power coupler designing and the HOM damping for the 400 MHz elliptical shaped parallel-bar cavity are discussed in detail.

FUNDAMENTAL INPUT POWER COUPLER DESIGN

In the parallel-bar cavity the fundamental deflecting mode has a strong transverse electric field between the bars on the beam axis where magnetic field is stronger around the bars at the top and bottom surfaces. The transverse electric field gives the main contribution to the net deflection seen by the beam. The field orientation of the electric field on the beam axis and magnetic field at the top surface are shown in Fig. 2.

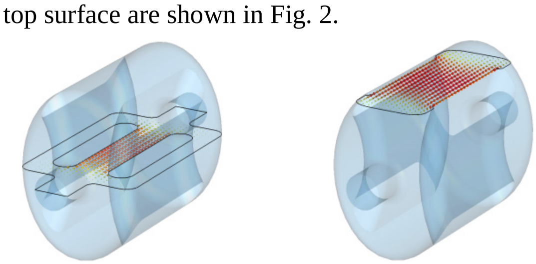

Figure 2: Electric field at mid plane (left) and magnetic field at top surface (right).

The LHC crab cavity requires an 8 MV transverse voltage for a single beam on one side of each interaction point. Assuming a maximum transverse voltage of 5 MV per cavity with a transverse [*R*/*Q*] of 263 Ω the input coupler will have an external Q (Q_{ext}) of ~10^6. The Q_{ext} is determined by considering beam loading and power required for microphonics compensation. It is also taken in to account the possible effect of mixing of the fundamental modes where both transverse and longitudinal electric field components are present due to cavity deformations [3]. A crabbing cavity operating at *0* phase experiences the maximum effect due to mode maxing. Based on the field orientation two input coupler options are considered for the elliptical shaped cavity as shown in Fig. 3.

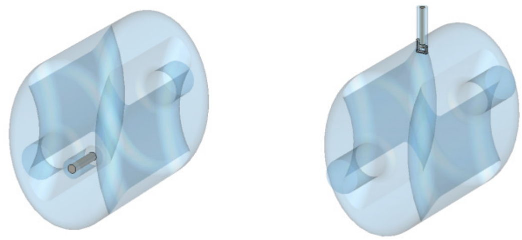

Figure 3: Coaxial input coupler (left) and a magnetic loop coupler (right).

The required Q_{ext} is achieved in both methods of coupling. In the first option a 50 Ω coaxial type coupler is used to couple to the transverse electric field at the plane of beam axis. The coupler is placed at the end plates near the beam axis where the highest electric field near a surface exists. However this method of coupling to the fundamental mode is critical due to comparatively low fields. This method of coupling also supports damping of some of the HOMs with fields near the beam pipe using the input power coupler.

As an alternate option a loop coupler is used to couple to the strong magnetic fields at the top surface. A loop of dimensions 1.2 cm × 2.7 cm attached to a 50 Ω coaxial coupler is placed perpendicular to the magnetic field lines between the bars to achieve the required coupling. Coupling to the electric field is preferred over stronger coupling achieved by magnetic loop coupler. Higher currents generated in the loop may lead to power losses due to surface heating; therefore requires substantial cooling to keep the heating at a minimum level.

HOM COUPLER DESIGN

The HOMs in the parallel-bar cavity are categorized [4] 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 couple to the beam (H_Z); that differs from the categorization in a conventional cavity. The non existence of any lower order modes (LOM) is one of the key features of this geometry that eliminates the requirement of notch filters. The wider separation between the modes gives fewer modes below the beam aperture cut-off frequency that needs to be considered for damping. Modes in an elliptical shaped cavity were measured using a prototype of 800 MHz.

800 MHz Parallel-Bar Cavity Prototype

A half scaled cavity with exact half dimensions of a 400 MHz was fabricated by Niowave Inc. The 800 MHz model was carved using an Al block with separate end plates clamped together as shown in Fig. 4. All the modes measured up to 4 GHz using a network analyzer was compared with the simulation results obtained from CST Microwave Studio. The modes were measured and identified using different coax type and loop type probe combinations. All the modes that were generated by the CST Microwave Studio were identified on the measured data and were in good agreement.

Figure 4: 800 MHz elliptical shaped cavity prototype.

The [R/Q] values shown in Fig. 5 are calculated for all the models in the 400 MHz elliptical shaped cavity. The mode separation between the two fundamental modes is 200 MHz.

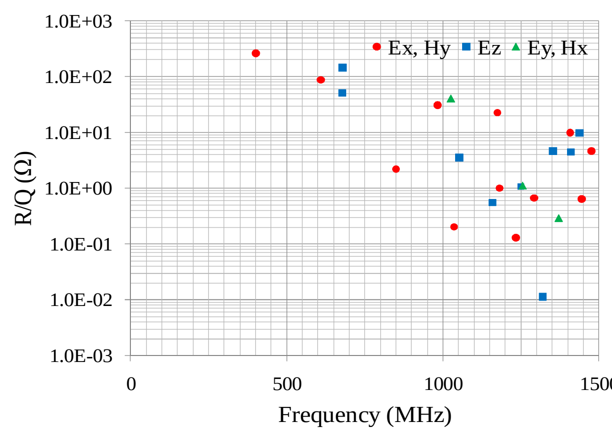

Figure 5: [*R/Q*] values for the 400 MHz elliptical shaped parallel-bar cavity.

The crab cavity proposed for the LHC luminosity upgrade requires a longitudinal impedance threshold of 20 kΩ and a 0.4 MΩ/m transverse impedance threshold for 2 identical cavities [5]. The corresponding Q_{ext} required to damp each mode to be below the threshold impedance is given by

$$Z_{Z,n} = \left[\frac{R}{Q}\right]_{Z,n} Q_{ext,n} \qquad (1)$$

$$Z_{T,n} = \frac{\omega_n}{c}\left[\frac{R}{Q}\right]_{T,n} Q_{ext,n} \qquad (2)$$

where $\left[\frac{R}{Q}\right]_Z$, $\left[\frac{R}{Q}\right]_T$ are for transverse and longitudinal modes respectively and ω is the frequency for each mode. The required Q_{ext} for all the modes calculated using Eqn. 1 and 2 are shown in Fig. 6. Most of the modes have higher Q_{ext} where some have considerably low Q_{ext} that requires strong coupling in order to damp them.

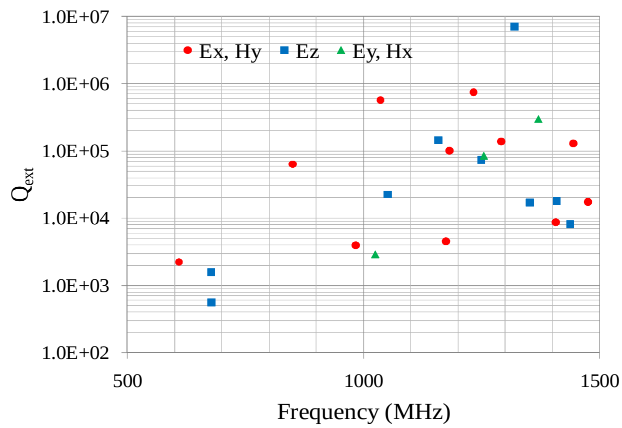

Figure 6: Required Q_{ext} for HOMs to achieve the specified damping.

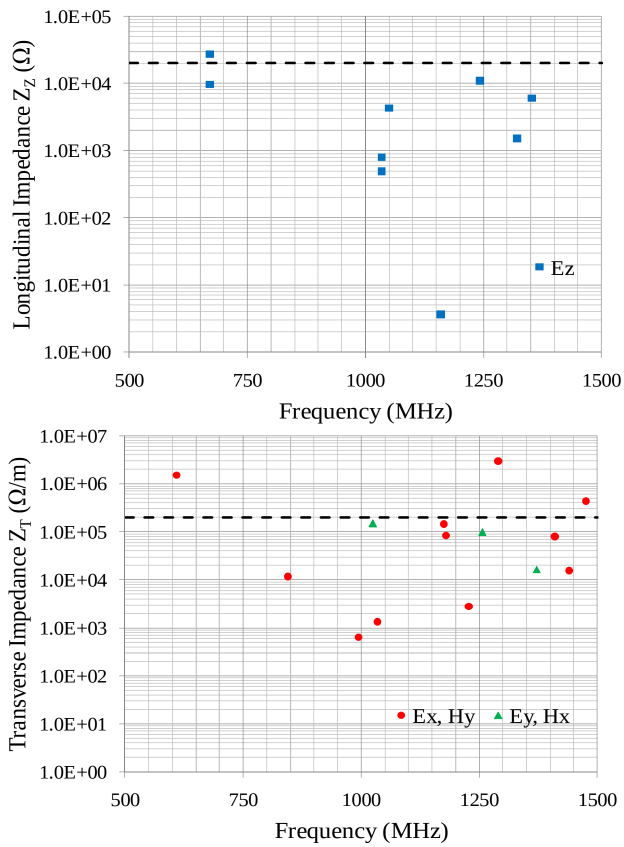

Figure 7: Longitudinal (top) and transverse (bottom) impedances of the damped modes.

The HOM damping is achieved with a series of coaxial couplers placed on the cavity surface. The positions of the couplers are determined by the field orientation of the modes to be damped. The complex nature of the fields in the HOMs requires a advanced scheme of couplers to damp them adequately. The HOM coupler configuration for the 400 MHz elliptical shaped cavity is shown in Fig. 8. In most of the modes the fields are between the bars and were damped using the couplers laced at the end walls. These modes were substantially damped without damping the fundamental operating mode of the parallel-bar cavity. Modes with higher fields between the cavity wall and the outer wall of the bars are damped easily with couplers placed on the side walls. Only fewer modes had fields dissipating in to the beam pipe.

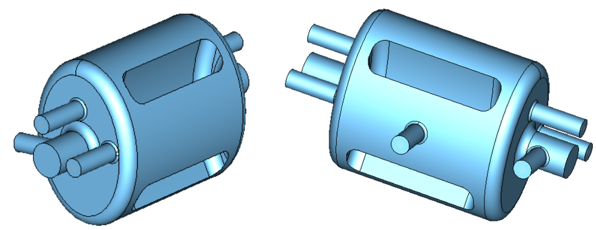

Figure 8: HOM coupler scheme for the elliptical shaped parallel-bar cavity.

Damped impedances achieved with the HOM coupler scheme for longitudinal and transverse modes are shown in Fig. 7. Most of the modes with a longitudinal electric field were damped successfully below the impedance threshold. Some of the modes with a transverse field configuration could not be damped to acceptable levels given by the impedance threshold. These modes have very low electric fields near the surface that makes it difficult to use electric coupling to damp them. Magnetic coupling with a loop coupler will be an alternative method to achieve the required damping.

CONCLUSION

The input power required to operate the parallel-bar cavity can be delivered with both coaxial and loop type couplers. Critical modes with higher [*R*/*Q*] that corresponds to lower Q_{ext} were identified. Some of the modes didn't achieve the required damping threshold and requires a coupler configuration with stronger damping. The HOM damping performed in here is preliminary and further improvements are ongoing. The geometry (C) in Fig. 1 removes the modes near the side walls and gives easier access to damp the modes with fields trapped between the bars. Furthermore a detailed analysis of multipacting at these couplers needs to be investigated.

ACKNOWLEDGEMENT

We would like to thank Niowave Inc. for providing the 800 MHz parallel-bar cavity prototype and Frank Marhauser for his valuable advice on HOM damping.

REFERENCES

[1] J.R. Delayen and H. Wang, Phys. Rev. ST Accel. Beams 12, 062002 (2009).
[2] Design of Superconducting Parallel-Bar Deflecting/Crabbing Cavities with Improved Properties, J.R. Delayen and S.U. De Silva, This proceedings.
[3] S.U. De Silva and J.R. Delayen, Proceedings of LINAC'10, Tsukuba, Japan (2010).
[4] S.U. De Silva and J.R. Delayen, Proceedings of IPAC'10, Kyoto, Japan, p. 3075 (2010).
[5] Impedance Effects During Injection, Energy Ramp & Store, E. Chapochnikova, 4th LHC Crab Cavity Workshop, CERN (2010).