

2021

HOM Damper Design for BNL EIC 197MHZ Crab Cavity

Binping Xiao

Jean R. Delayen

Old Dominion University, jdelayen@odu.edu

Subashini U. De Silva

Old Dominion University, pdesilva@odu.edu

Z. Li

R. Rimmer

See next page for additional authors

Follow this and additional works at: https://digitalcommons.odu.edu/physics_fac_pubs



Part of the [Elementary Particles and Fields and String Theory Commons](#), and the [Engineering Physics Commons](#)

Original Publication Citation

Xiao, B., Delayen, J.R., De Silva, S.U., Li, Z., Rimmer, R., Verdu-Andres, S., Wu, Q. (2021) *HOM damper design for BNL EIC 197Mhz crab cavity* [Conference paper]. 2021 International Conference on RF Superconductivity, Virtual/East Lansing, Michigan. <https://www.osti.gov/biblio/1827722>

This Conference Paper is brought to you for free and open access by the Physics at ODU Digital Commons. It has been accepted for inclusion in Physics Faculty Publications by an authorized administrator of ODU Digital Commons. For more information, please contact digitalcommons@odu.edu.

Authors

Binping Xiao, Jean R. Delayen, Subashini U. De Silva, Z. Li, R. Rimmer, S. Verdu-Andres, and Qiong Wu

HOM DAMPER DESIGN FOR BNL EIC 197MHZ CRAB CAVITY

B. Xiao

Submitted to the 2021 International Conference on RF Superconductivity Conference
to be held at Virtual/Hosted by Michigan State University
June 28 - July 2, 2021

October 2021

Electron-Ion Collider

Brookhaven National Laboratory

U.S. Department of Energy

USDOE Office of Science (SC), Nuclear Physics (NP) (SC-26)

Notice: This manuscript has been authored by employees of Brookhaven Science Associates, LLC under Contract No. DE-SC0012704 with the U.S. Department of Energy. The publisher by accepting the manuscript for publication acknowledges that the United States Government retains a non-exclusive, paid-up, irrevocable, world-wide license to publish or reproduce the published form of this manuscript, or allow others to do so, for United States Government purposes.

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or any third party's use or the results of such use of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof or its contractors or subcontractors. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

HOM DAMPER DESIGN FOR BNL EIC 197MHZ CRAB CAVITY*

Binping Xiao^{1†}, J. R. Delayen^{2,3}, S. U. De Silva², Z. Li⁴, R. Rimmer³, S. Verdu-Andres¹, Qiong Wu¹

¹Brookhaven National Laboratory, Upton, New York 11973-5000, USA

²Center for Accelerator Science, Old Dominion University, Norfolk, VA 23529, USA

³Jefferson Lab, Newport News, VA 23606, USA

⁴SLAC, Menlo Park, CA 94025, USA

Abstract

The interaction region (IR) crab cavity system is a special RF system to compensate the loss of luminosity due to a 25 mrad crossing angle at the interaction point (IP) for Brookhaven National Lab electron ion collider (BNL EIC). There will be six crab cavities, with four 197 MHz crab cavities and two 394 MHz crab cavities, installed on each side of the IP in the proton/ion ring, and one 394 MHz crab cavity on each side of the IP in the electron ring. Both rings share identical 394 MHz crab cavity design to minimize the cost and risk in designing a new RF system, and it will be scaled from 197 MHz crab cavity. In this paper, the higher order mode (HOM) damper design for 197 MHz crab cavity is introduced.

INTRODUCTION

The EIC crab cavities are designed to provide local crabbing scheme (crab before entering IP and de-crab after leaving IP) in horizontal plane with 25mrad full crossing angle for both electrons and hadrons. Based on beam-beam simulations, there are three possible operation scenarios under consideration, hereafter summarized quoting the necessary total crabbing voltage per IP per side:

1, 24 MV deflecting voltage from 197 MHz crab cavity for HSR, and 2.9 MV deflecting voltage from 394 MHz crab cavity for ESR. This is the baseline.

2, 33.83 MV deflecting voltage from 197 MHz crab cavity, and -4.75 MV from 394 MHz crab cavity for HSR, and 2.9 MV deflecting voltage from 394 MHz crab cavity for ESR.

3, increase the voltages by a factor of 20%.

To meet the requirement, we consider putting two 197 MHz crab cavities in one 197 cryomodule and put one 394 MHz crab cavity in one 394 cryomodule. For HSR, two 197 cryomodules and two 394 cryomodules are used per IP per side; for ESR, one 394 cryomodule is used per IP per side, with ESR and HSR 394MHz cryomodules identical.

In the EIC hadron storage ring (HSR), for impedance budget consideration, 2 IPs are assumed, see Fig. 1, with four 197 MHz crab cavities per IP per side and total sixteen 197 MHz crab cavities in HSR. The longitudinal impedance budget per 197 MHz crab cavity is set at 10.0 k Ω , with circuit definition used in this paper unless otherwise noted, and the transverse impedance budget is 0.25 M Ω /m

per cavity at crab cavity locations with 1300 m beta function. HOMs up to 2 GHz were evaluated. Comparing with the LHC impedance budget requirement, both longitudinal and transverse impedance budgets are tighter. The LHC double quarter wave (DQW) [1-3] or RF-dipole (RFD) [4, 5] HOM damper designs cannot be directly adopted to EIC crab cavities. New HOM damper designs for these two types of crab cavities are shown in this paper.

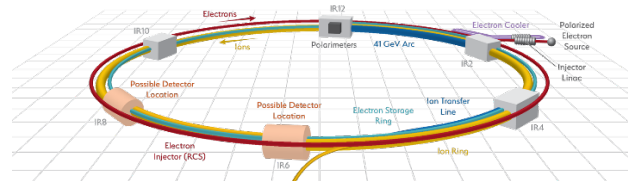


Figure 1: Possible locations of EIC crab cavities include IR6 and IR8.

Table 1: Key parameters of 197MHz crab cavities.

Property	Specs	DQW	RFD
f_0 [MHz]	197.0	197.0	197.0
1 st HOM [MHz]		304.2	345.9
Geometry factor [Ω]		68.2	99.0
R/Q [Ω , acc. def.]		1159.7	1148.0
V_t [MV]	11.5	11.5	11.5
E_{peak} [MV/m]	≤ 45	44.8	44.0
B_{peak} [mT]	≤ 80	69.5	78.0
Cavity length [mm]	≤ 1500	821.8	941.0
Cavity height [mm]	<900 ID	452.5	587.0
Cavity width [mm]		584.4	587.0
Tuning range [MHz]	≥ 0.8	≥ 0.8	± 1.3
FPC Q_{ext}	3×10^6	3×10^6	3×10^6

DQW WITH HOM DAMPER

To minimize the peak magnetic field at certain deflecting voltage, the EIC DQW crab cavity is elongated along beampipe direction with an ovaloid profile while comparing with HL-LHC DQW. A small angle in the inner conductor wall allowed minimizing peak magnetic field further. A sufficiently large radius to blend the capacitive plate edges helped reaching smaller peak electric field. The corners of the cavity were also rounded to further reduce peak fields. The geometry of the EIC DQW cavity is shown in Fig. 2. Table 1 shows the key parameters of 197 MHz DQW.

To damp the first HOM at 304.2 MHz, a large (>500 mm rectangular width) HOM port is needed, we choose 530 mm \times 75 mm rectangle. 75 mm is chosen to provide enough damping. To ease the fabrication, this HOM port is designed to replace the cone area of the bare cavity. A

* Work supported by Brookhaven Science Associates, LLC under U.S. DOE contract No. DE-AC02-98CH10886, and by Jefferson Science Associates, LLC under U.S. DOE Contract No. DE-AC05-06OR23177.

† binping@bnl.gov

rectangular waveguide absorber is going to be placed at the end of this waveguide. To keep the symmetry, on the other side of the cavity, the cone area is also replaced by such a large rectangle, with the difference that instead of the HOM port, this rectangle is shorted. The large HOM waveguide damper is used to damp both longitudinal and horizontal modes, and the small waveguide, 240 mm × 50 mm rectangle to coax damper is used to damp both longitudinal and vertical modes.

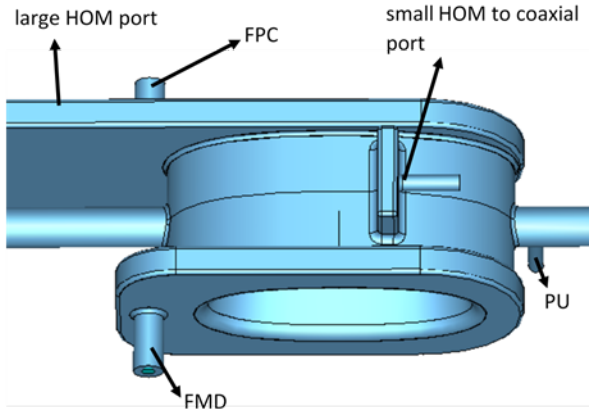


Figure 2: EIC 197 MHz DQW cavity with HOM dampers, fundamental power coupler (FPC), pickup coupler (PU), and possible fundamental mode damper (FMD).

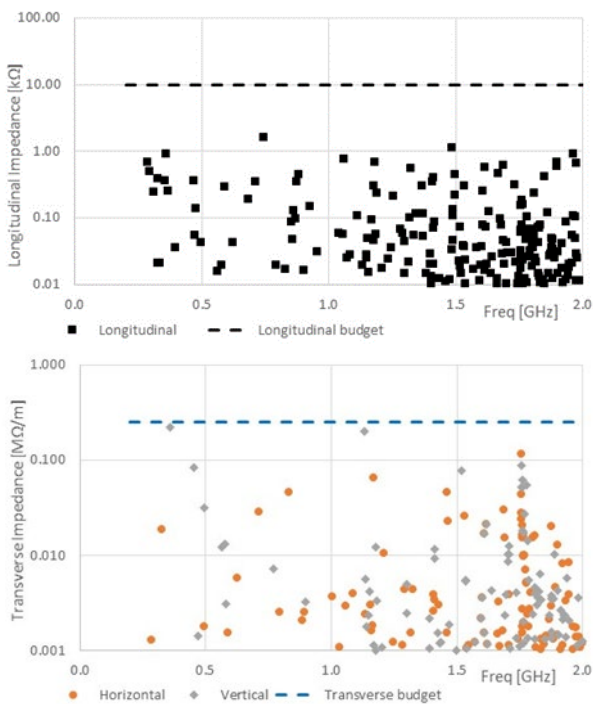


Figure 3: EIC 197 MHz DQW cavity HOM impedances.

The EIC 197 MHz DQW crab cavity HOM impedances of all modes up to 2 GHz are shown in Fig. 3, with the top longitudinal impedances, and the bottom transverse impedances. The dash lines are the impedance budgets. The highest longitudinal impedance is 1.62 kΩ with 105 loaded Q at 742 MHz, the highest transverse impedance is 0.22 MΩ/m with 1985 loaded Q at 360 MHz.

For the HOM power calculation, 10 mm off center is used to ensure HOM power from transverse modes are not underestimated. The frequencies of HOMs are shifted within $\pm 0.2\%$, and cancellation due to phase difference between different HOMs is not taken into account. All these ensured the worst-case scenario estimation. The 290 bunches with 6 cm bunch length and 0.74 A current case produces the highest HOM power at 3.2 kW, with 86% from the longitudinal modes.

RFD WITH HOM DAMPER

The LHC crab cavity is designed to be a compact square shaped cavity to fit between the two parallel beam pipes with a separation of 194 mm. The EIC RFD crab cavity is designed with a cylindrical outer conductor similar to several proof-of-principle cavities that have been previously designed and prototyped, see Fig. 4. Table 1 shows the key parameters of 197 MHz RFD.

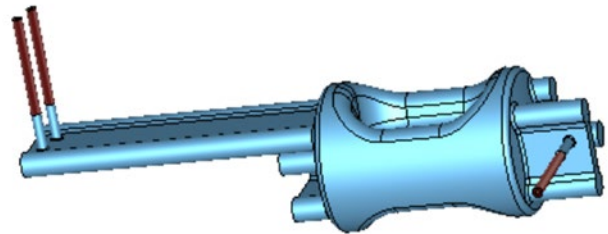


Figure 4: EIC 197 MHz RFD cavity with four dogbone ports and three coax HOM absorbers. The left horizontal HOM (HHOM) dogbone waveguide is terminated with two coax absorbers and the right vertical HOM (VHOM) dogbone waveguide is terminated with one coax absorber.

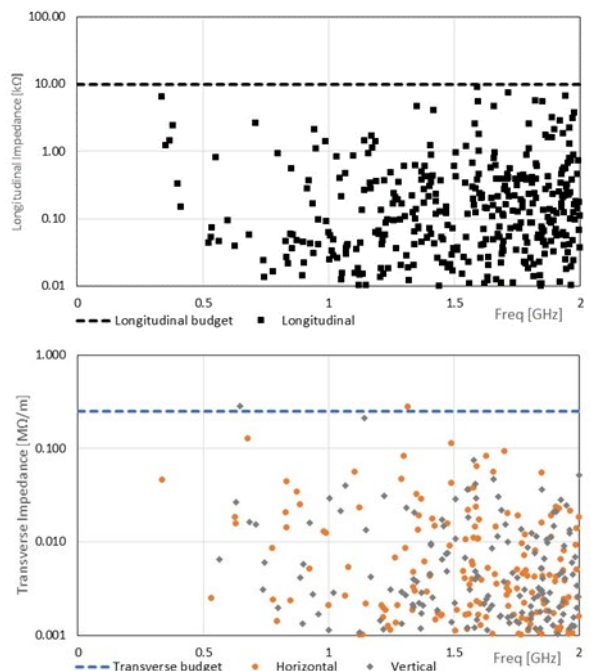


Figure 5: EIC 197 MHz RFD cavity HOM impedances.

The 197 MHz RFD cavity is designed with two HOM waveguides as shown in Fig. 4 that suppress the HOM

modes up to 2 GHz. The RFD cavity is designed with compact dogbone shaped waveguides to reduce the cut-off frequency of the waveguide for improved HOM propagation and to simplify the manufacturability. Four identical waveguide stubs are placed in the endplates of the cavity that simplify the fabrication of the RFD cavity. Similar to the LHC crab cavity design, the VHOM waveguide coupler doesn't couple to the fundamental mode. The HHOM waveguide couples to the fundamental operating mode therefore made sufficiently long to reduce the fundamental mode fields at the load.

In the EIC critical design report (CDR), the dogbone waveguide stubs are tapered to transition into rectangular shaped waveguides to the loads. The waveguides are placed at the end plates in the low field region of the cavity and do not lead to any field enhancement at the edges in the waveguide stubs. This HOM damper design is currently our baseline.

In this paper, the HOM damper is further optimized so that coax absorbers can be used. Two coax absorbers are used on the HHOM waveguide, with one 60 mm away from the electric short and 65 mm off-center, and the other 90 mm away from the electric short and 40 mm off-center. One coax absorber is used on the VHOM waveguide and is 90 mm away from the electric short and 40 mm off-center. The HOM impedances are shown in Fig. 5, with longitudinal impedances meet the impedance budget, and two transverse HOMs slightly above the impedance budget. The highest longitudinal impedance is 8.89 k Ω with 5.67e4 loaded Q at 1.59 GHz, the highest transverse impedance is 0.29 Ω /m with 805 loaded Q at 805 MHz. Comparing with RFD design in CDR, as well as DQW design in CDR, this design shows comparable transverse impedance, while the longitudinal impedance is higher. This is due to the change of using coax absorbers, instead of a waveguide absorber, to damp some of the longitudinal modes.

For the HOM power calculation, the same assumptions as the DQW cavity HOM power calculation are used. The 290 bunches with 6 cm bunch length and 0.74 A current case produces the highest HOM power at 4.6 kW, with 90% from the longitudinal modes.

CONCLUSION

The peak magnetic field of DQW is 10% lower while comparing with that of RFD. Currently the RFD design with two waveguide absorbers, shown in the CDR, is the baseline. In this paper, RFD design is further optimized so that only coax absorbers are used. The max transverse HOM impedance in these two cavities are about the same, with DQW one slightly smaller. The max longitudinal HOM impedance of RFD design higher than that of DQW, while both meet the EIC specification. Please note some levitation on longitudinal impedances were brought by the change from waveguide to coax absorbers. The HOM power for DQW design is 3.2 kW and for RFD is 4.6 kW. In short, the RF design of RFD and DQW are comparable.

The length of bare DQW cavity is 13% shorter, while with HOM damper, their lengths are comparable.

We choose RFD over DQW as the baseline of EIC 197 MHz crab cavity because RFD design is closer to LHC design; RFD for LHC is for horizontal crabbing, which is the same as for EIC; and based on an evaluation effort led by Joe Preble at JLab, RFD mechanical design is more mature, and RFD is more advanced and initial fabrication, processing, and testing evaluations have been completed.

REFERENCES

- [1] B. Xiao *et al.*, *Design, prototyping, and testing of a compact superconducting double quarter wave crab cavity*, Phys. Rev. Spec. Top. Accel. Beams **18**, 4, 041004 (2015). <http://link.aps.org/doi/10.1103/PhysRevSTAB.18.041004>.
- [2] S. Verdú-Andrés *et al.*, *Design and vertical tests of double-quarter wave cavity prototypes for the high-luminosity LHC crab cavity system*, Physical Review Accelerators and Beams **21**, 8, 082002 (2018). <http://link.aps.org/doi/10.1103/PhysRevAccelBeams.21.082002>.
- [3] R. Calaga *et al.*, *First demonstration of the use of crab cavities on hadron beams*, Physical Review Accelerators and Beams **24**, 6, 062001 (2021). <http://link.aps.org/doi/10.1103/PhysRevAccelBeams.24.062001>.
- [4] S. U. D. Silva, J. R. Delayen, *Cryogenic test of a proof-of-principle superconducting rf-dipole deflecting and crabbing cavity*, Phys. Rev. Spec. Top. Accel. Beams **16**, 082001, (2013). <http://dx.doi.org/10.1103/PhysRevSTAB.16.082001>
- [5] S. U. De Silva, J. R. Delayen, *Design evolution and properties of superconducting parallel-bar rf-dipole deflecting and crabbing cavities*, Phys. Rev. Spec. Top. Accel. Beams **16**, 1, 012004 (2013). <http://link.aps.org/doi/10.1103/PhysRevSTAB.16.012004>.