

HOM DAMPER DESIGN FOR BNL EIC 197 MHz CRAB CAVITY*

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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.

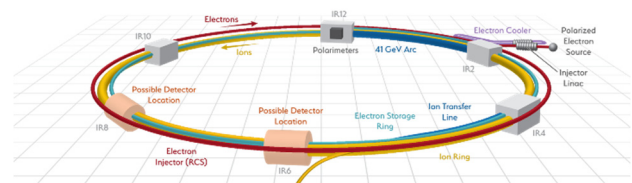


Figure 1: Possible locations of EIC crab cavities include IR6 and IR8.

Table 1: Key Parameters of 197 MHz 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

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designed to replace the cone area of the bare cavity. A 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.

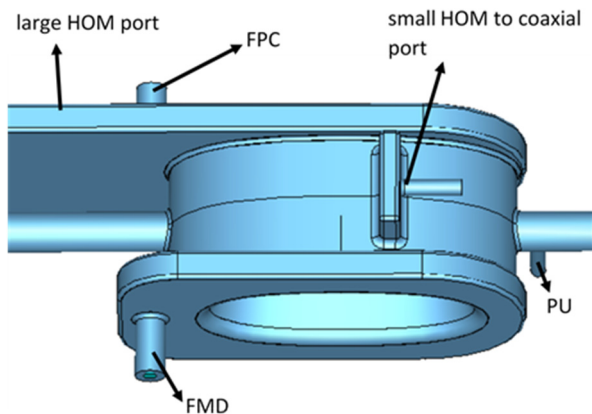


Figure 2: EIC 197 MHz DQW cavity with HOM dampers, fundamental power coupler (FPC), pickup coupler (PU), and possible fundamental mode damper (FMD).

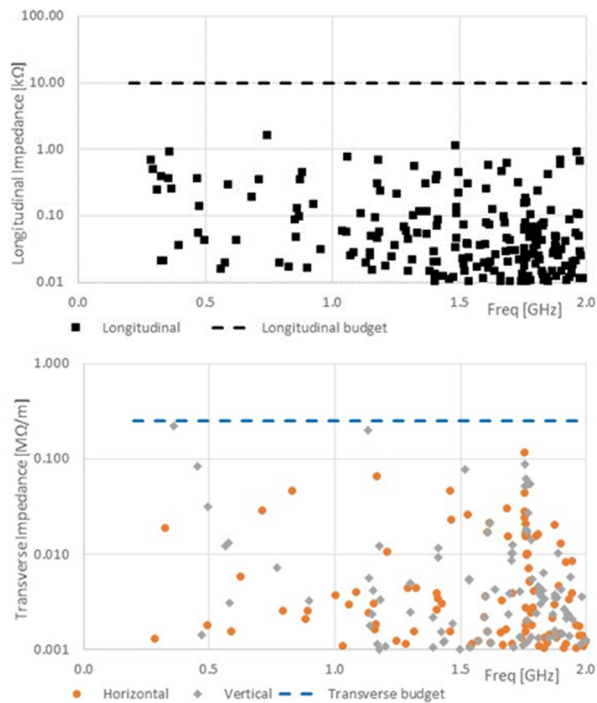


Figure 3: EIC 197 MHz DQW cavity HOM impedances.

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 ±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.

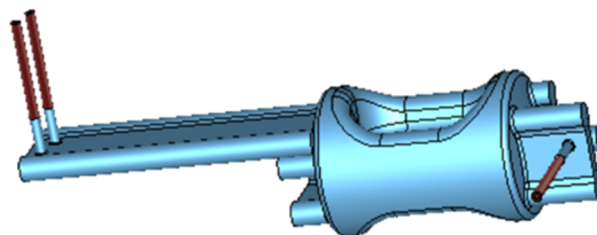


Figure 4: EIC 197 MHz RFD cavity with four dogbone ports and three coax HOM absorbers. The left horizontal HOM (HHOM) dogbone waveguide is terminated with two coax absorbers and the right vertical HOM (VHOM) dogbone waveguide is terminated with one coax absorber.

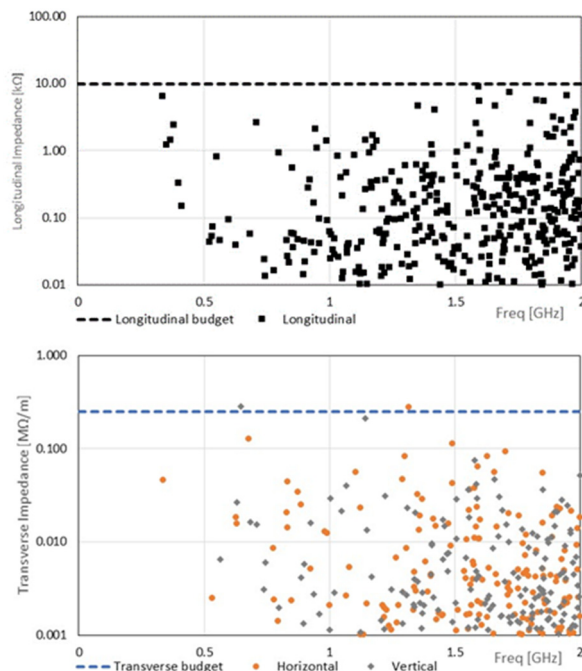


Figure 5: EIC 197 MHz RFD cavity HOM impedances.

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.

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