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HOM POWER IN THE EIC CRAB CAVITY SYSTEM*

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Abstract

Two types of crab cavities, one at 197 MHz and the other at 394 MHz, are designed to compensate the loss of luminosity due to a 25 mrad crossing angle at the interaction point (IR) in the Electron Ion Collider (EIC). The Higher Order Mode (HOM) damper designs of the EIC differs from the LHC designs since in the EIC the impedance budget is tighter, especially longitudinally, and in the EIC the HOM power is much higher due to the short and high intensity electron and ion beam. In this paper, HOM power in these two cavities is evaluated and optimized.

INTRODUCTION

The EIC crab cavities are designed to provide local crabbing scheme in horizontal plane for two possible interaction points (IPs), with 197 MHz and 394 MHz for hadron storage ring (HSR) and 394 MHz for electron storage ring (ESR). There are many challenges, including large cavity size, longitudinal and transverse space constraints in both IPs, tight impedance budget, beyond the state-of-art low level RF (LLRF) control specs. HOM damper design to mitigate the HOM power produced in these cavities is one of them. In this paper, the HOM power in 197MHz HSR and 394 MHz ESR crab cavities is studied in detail.

The 394 MHz HSR crab cavity produces less HOM power than 394 MHz ESR, it will be studied in detail later.

197 MHZ HSR CRAB CAVITY

The 197 MHz HSR crab cavity HOM damper designs were discussed in detail previously. Two designs were proposed, one with waveguide absorbers, Figure 1a [1], and the other with coaxial absorbers, Figure 1b [2]. Coaxial design was chosen over the waveguide design due to the following reasons:

1. The waveguide design requires further R&D effort on the waveguide load. However, the coaxial design is a less complex design that uses an RF window and a coaxial cable and with commercially available coaxial loads. The coaxial cable can be a rigid similar to the LHC crab cavity [3, 4] or a flexible similar to the FPC cable used in LCLS-II [5]. Both options are capable of handling similar power levels of the EIC 197 MHz crab cavity.
2. The waveguide loads are large in size and requires to be placed inside the cryomodule as part of the cavity system. The coaxial loads can be placed outside the cryomodule, with its weight to be 2.3 kg (active water cooling required) or 26 kg (oil-cooled with blower assembly). The estimated weight of the Cu peg board and absorber material for the waveguide load will be ~47 kg, relatively higher in comparison to the coaxial cable and load.
3. The waveguide design requires transition from dogbone to rectangular waveguide, and 180 degrees bending on rectangular waveguide, while the coaxial design uses straight dogbone.
4. The RF performance, as well as the total length, of these two designs are similar. There were concerns about the possible impedance enhancement on the coaxial design, detailed error analyses cleared these concerns.
5. While the waveguide design can handle much higher HOM power in comparison to the coaxial design, the coaxial design can handle twice the HOM power that can be generated in the 197 MHz crab cavity.
6. The waveguide load design uses 1” sized with 0.1” separation. The load has 17 tiles across 20 rows in a ramped configuration. A smaller scale (4”×7”) has been designed and a prototyped being fabricated for HZB bERLinPro and Bessy-VSR SRF cavities by J. Guo and the team at JLab [6]. The large-scale configuration increases the complexity in terms of brazing the tiles into Cu peg board.
7. Waveguide design requires bellows of 50 cm × 8 cm with Cu coating. Bellows of this scale with Cu coating has not been fabricated before and increases the complexity of the waveguide design. Also, the large-scale load makes the anchoring of the load difficult with issues in extracting heat.
8. The current design of the waveguide load material of AlN-SiC composite (STL-100) is expensive compared to the other waveguide load material.
9. Mechanical support for the waveguide loads also add to the design complexity including shipping and transportation.

For the HOM power calculation for coaxial design, 10 mm off center is used to ensure HOM power from transverse modes is 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 estima-

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tion. HOMs up to 2 GHz were simulated using CST Microwave Studio with Eigen mode, modes above 2GHz will propagate out of the beampipe. Beam spectrum was calculated using Fourier transform of the HSR bunch structure and HOM power was calculated using the above results in frequency domain. The 290 bunches with 6 cm bunch length and 0.74 A current case produces the highest HOM power at 4.4 kW, with 88% from the longitudinal modes. The power on each coaxial load is no more than 2.2kW, with less than 0.1kW from fundamental mode.

HOM window and RF cable similar to LHC crab cavity design [7] will be used. The LHC crab cavity HOM window was designed for 1kW power and tested up to 4kW in CW with full reflection, further R&D is needed to improve the power handling. RF simulations with HOM windows, RF cables and artificial coaxial loads that have VSWR similar to those commercially available were performed, together with detailed error analyses, fluctuations on HOM power in these simulations are acceptable.

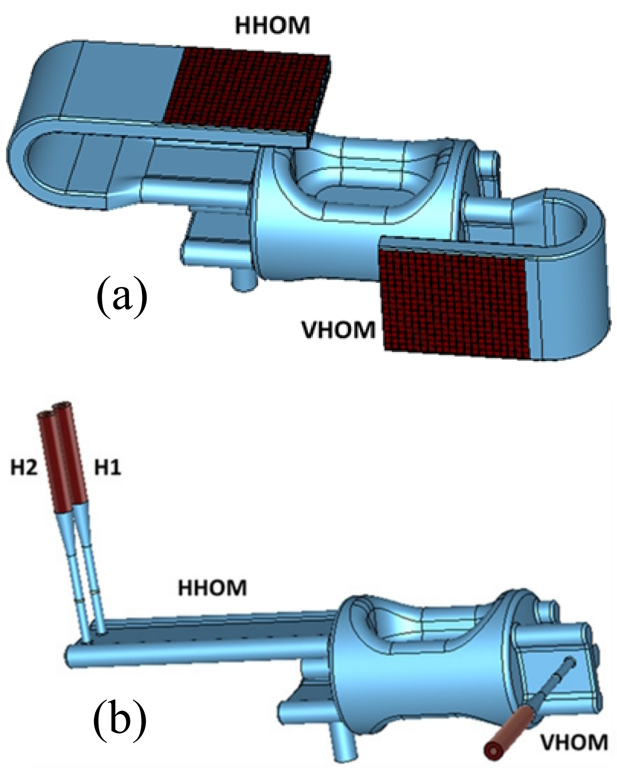

Figure 1: EIC 197 MHz crab cavity with (a) waveguide absorbers (b) coaxial absorbers.

394 MHZ ESR CRAB CAVITY

Two 394 MHz ESR crab cavity designs were proposed, one wide open waveguide (WOW) type with SiC beamline absorber (Figure 2a) and the other with 4 on-cell waveguide absorbers (Figure 2b).

Quick HOM power calculation was done using the wake impedance from wake simulation with 7mm bunch length and the assumption that all HOMs were damped to small enough loaded Qs so that resolving the possible trapped high Q modes below beampipe cutoff frequencies is not needed. Two methods were used and cross checked to calculate the HOM power, one directly from the integrated wake loss factor, and the other integration of HOM power in frequency domain using real part of wake impedance and beam spectrum. Mesh convergence study was done to minimize the numeric noise in the wake potential so that the real part of the wake impedance can be positive below 14GHz. Case with 1160 bunches with 7 mm bunch length and 2.5 A current is considered here. The bare WOW type cavity (without SiC absorbers and transitions) produces 69kW HOM power. With transitions and SiC absorbers, as shown in Figure 2a, it will produce more HOM power at 179kW. While for the cavity with 4 waveguide absorbers shown in Figure 2b, the HOM power is around 55 kW, much smaller than the WOW type design thus it is more favorable. The reason that the cavity with 4 waveguide absorbers produces higher HOM power while comparing with WOW type design is that longer cavities tend to have larger loss factor. The cavity with 4 waveguide absorbers has endplates and on-cell waveguide absorbers, thus it is shorter while comparing with WOW design which does not have endplates, and the SiC absorbers need to be far away from the cavity due to fundamental power loss. Also crab cavity tends to produce more HOM power while comparing with single cell elliptical shape accelerating cavity, since crab cavity is more like a strong coupled multi-cell cavity for longitudinal components, thus larger loss factor.

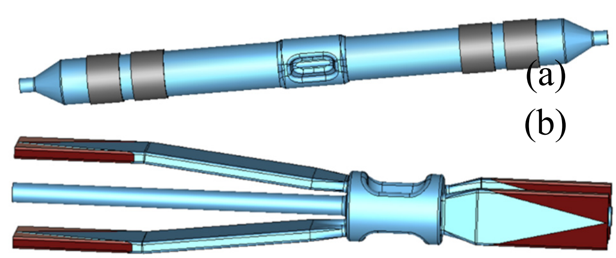

Figure 2: 394 MHz crab cavity designs: (a) WOW type with SiC beamline absorbers, and (b) 4 on-cell waveguide absorbers type.

Detailed simulation on the power flow to each port is done to the design with waveguide absorbers. In this simulation, two HHOM waveguides (on the left of Figure 2b), two VHOM waveguides (on the right of Figure 2b) and two beampipe ports (one on HHOM side and one on VHOM side) are set as the "port" with 5 port modes on each, and all these ports are set as "open boundary". 7 mm bunch length with 2.752e-8 C charge (corresponding to 2.5A beam current for 1160 bunches) that travelling from HHOM side to VHOM side is used. 100m wake length is used. The power coming out of the beampipe on HHOM side is 4.44 kW, of the beampipe on VHOM side is 6.65 kW, of the HHOM port is 10.32 kW each, and of the VHOM port is 11.86 kW each. The total HOM power is 54.24kW, close to our previous estimation.

While the beam direction is reversed, from VHOM side to HHOM side, the power going out of the HHOM side will be higher. Here 50m wake length is used to reduce the simulation time. The power coming out of the beampipe on

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HHOM side is 5.13 kW, of the beampipe on VHOM side is 3.96 kW, of the HHOM port is 11.86 kW each, and of the VHOM port is 10.46 kW each. The total HOM power is 53.73 kW.

Eigen mode simulations up to 2 GHz were also done to evaluate dangerous modes in the design with waveguide absorbers (as well as to ensure the design meets the impedance budget, which is not covered by this paper) , modes above 2 GHz will propagate out of the beampipe. Two modes produce 10 kW HOM power in total, with one at 590.5 MHz, 14 loaded Q and 241 Ω shunt impedance that produces 3.7 kW, and the other at 691.1 MHz with 15 loaded Q and 406 Ω shunt impedance that produces 6.3 kW. There are three other modes that produce more than 1 kW HOM power each, at 604.0 MHz, 1576.7 MHz and 1967.9 MHz. Further optimization will be done focusing on these modes.

Cavity with 6 waveguide absorbers, 3 on each side, is not suitable since it will complex the mechanical design within limited space, it is more difficult to evenly distribute the HOM power in 6 waveguide absorbers, and the VHOM side waveguides need to be longer to attenuate the fundamental mode.

Further optimizations on the 394MHz design are on-going to balance the ratio between peak electric field and peak magnetic field, to get better multipole components results and to lower the HOM power. This design is preliminary, detailed RF/thermal/mechanical coupled simulations will follow, together with the design of waveguide absorber, or alternative waveguide to coaxial absorber design if feasible, as well as tuner, fundamental power coupler (FPC), stiffener (if needed), helium vessel, etc.

SUMMARY

HOM power in the EIC crab cavity systems were studied. For 197MHz HSR crab cavity, coaxial design was chosen over waveguide design due to its engineering simplicity, cost efficiency, commercially available or previously proved components, while the power handling capability is less but acceptable with certain margin. For 394MHz ESR crab cavity, design with 4 on-cell waveguide absorbers is preferred over WOW type design, majorly due to lower HOM power produced in this design.

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