NEW HOM COUPLER DESIGN FOR HIGH CURRENT SRF CAVITY*

Wencan Xu[#,1], I. Ben-Zvi[1,2], S. Belomestnykh[1], H. Hahn[1], E.C.Johnson[1,2]
1) Collider-Accelerator Department, Brookhaven National Lab, Upton, NY 11973, US
2) Physics &Astronomy Department, Stony Brook University, Stony Brook, NY 11794, USA

Abstract

Damping higher order modes (HOMs) significantly to avoid beam instability is a challenge for the high current Energy Recovery Linac-based eRHIC at BNL. To avoid the overheating effect and high tuning sensitivity, current, a new band-stop HOM coupler is being designed at BNL. The new HOM coupler has a bandwidth of tens of MHz to reject the fundamental mode, which will avoid overheating due to fundamental frequency shifting because of cooling down. In addition, the S21 parameter of the band-pass filter is nearly flat from first higher order mode to 5 times the fundamental frequency. The simulation results showed that the new couplers effectively damp HOMs for the eRHIC cavity with enlarged beam tube diameter and 2 120° HOM couplers at each side of cavity. This paper presents the design of HOM coupler, HOM damping capacity for eRHIC cavity and prototype test results.

INTRODUCTION

The electron-proton collider eRHIC at Brookhaven National Laboratory will employ 224 five-cell superconducting cavities to accelerate the 3.5 nC bunches in 50 mA electron current to 5 to 30 GeV for collision with 250 GeV protons in RHIC [1]. The electrons will be accelerated in a pre-injector linac and then will pass six times around RHIC tunnel, gaining energy from two super-conducting RF (SRF) linacs located in two of RHIC's straight sections. The electron energy will be recovered in the linacs after the collision. The machine will operate in CW mode. In the ERL prototype [2], the HOMs are damped with room temperature ferrite absorbers located at the end of beam tubes. Much was learned from the prototype and the study of the ferrite properties has been reported previously [3].

To achieve the high damping requirements of eRHIC, there are at least two main aspects to be studied. The first aspect is to design a cavity with the capability of coupling HOMs out of the cavity, which has been done with larger beam tube to propagate HOMs but not the fundamental mode. In section II, a brief summary of the eRHIC cavity design is presented. The second aspect is to damp the HOMs. The room temperature ferrite damper has been proven to be robust. However, given the aim for a compact linac by putting several cavities in the same cryostat, we plan to use antenna style HOM couplers. This paper is focused on the design and testing of new HOM coupler for eRHIC, detailed in sections III and IV.

CAVITY DESIGN

The 703.75 MHz, 5-cell cavity designed for eRHIC is shown in Fig.1. It was optimized to lower the Bpeak/Eacc and increase the (R/Q)*G for the fundamental mode. The optimized cavity has a low-loss shape with the wall angle of about 2.5 degrees. The cell-to-cell coupling is 3.02% and the beam tube radius is 11 cm. These parameters were optimized for propagation of all HOMs while attenuating the fundamental mode. There are two tapers at both ends of the cavity to eliminate the crosstalk between cavities in a string. Table 1 compares parameters of the fundamental mode for BNL3 cavity and the BNL I cavity [4], the cavity used in the BNL ERL prototype. The beam-break-up simulation showed that the BNL3 cavity is qualified for the 300mA ERL [5].

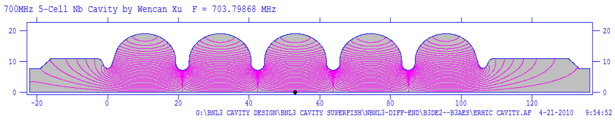

Figure 1: BNL3 cavity in superfish.

Table 1: 704MHz cavity: BNL3 and BNLI

Parameters	**BNLI**	**BNL3**
Geometry factor	225	283
(R/Q)/Cavity[Ω]	404	506.3
Epeak/Eacc	1.97	2.46
Bpeak/Eacc[mT/MV/m]	5.78	4.27
Coupling factor[%]	3.00	3.02

TWO-STAGE HOM COUPLER

TESLA-type HOM Coupler

The function of a HOM coupler is to extract HOM power induced by electron beams while rejecting the fundamental mode power. The TESLA-type HOM coupler, is widely used at many facilities, such as European XFEL [7] and SNS [8]. There are three physical parts in this type of HOM coupler as followed.

- A notch filter is used to reject the fundamental mode power.
- A coupling antenna is used to couple beam-excited HOM power outside of the end cell of cavity.
- A pickup probe connected with cable is used to propagate the HOM power outside the HOM coupler.

---

*Work is supported by Brookhaven Science Associates, LLC under Contract No. DE-AC02-98CH10886 with the U.S. DOE
#WXU@BNL.GOV

One such TESLA-type HOM coupler was designed for the five-cell 703.75 MHz BNL1 cavity at BNL by AES [9]. The broadband performance of the HOM coupler is shown in Fig.2. There is one notch frequency at 703.75 MHz with very narrow bandwidth, and the performance above around 2.5 GHz becomes worse. However, due to the high sensitivity of the notch frequency and possible overheating of the pickup probe, the ferrite HOM damper was chosen. Similar problems also happened at SNS at Oak Ridge National Laboratory [8]. So a new HOM coupler needed to be designed to overcome such problems.

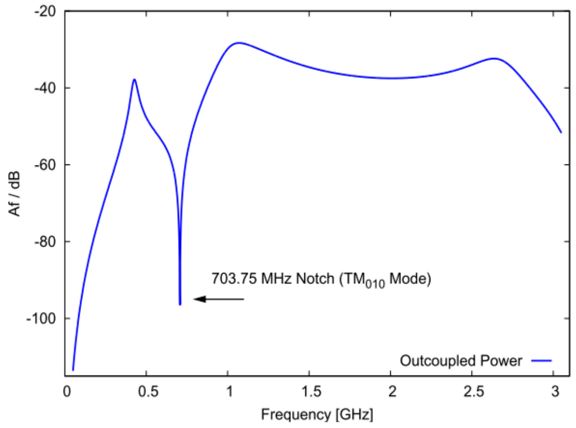

Figure 2: Performance of TESLA HOM coupler for BNL1 cavity.

Two-Stage HOM Coupler Design with Double Notch Frequency

A new compact HOM coupler for eRHIC cavities should satisfy three main requirements:

- either reduce the notch frequency sensitivity or broaden the notch filter band, so that the frequency shift due to cooling down or related technical issues are not a concern;
- overcome overheating of the pickup probe and provide efficient cooling of the inner conductor;
- allow propagation of all HOMs outside the cryostat, where they can be damped at room temperature.

Adding the second notch filter near the fundamental mode frequency broadens the notch filter's bandwidth. From the circuit theory we know that to obtain two notch frequencies, there must be at least two capacitors and two inductors. In addition, the separation between the first higher order mode (about 817 MHz) and the fundamental mode (703.75 MHz) is small, hence the higher notch frequency cannot be too close to the first higher order mode, otherwise the latter may not be damped well. One such HOM coupler, called two-stage HOM coupler, has been designed as shown in Fig.3. There are three physical differences comparing with TESLA-type HOM coupler.

- The two-stage HOM coupler works like a transmission line. One end of the HOM coupler is welded to the beam pipe. The HOM is coupled through an electric probe, a conductive sphere at the end of which serves to increase the coupling efficiency. The impedance of the other end of the HOM coupler is 50 Ohm, matched to a coaxial cable used to propagate the HOM power outside of the cryostat and damp it at room temperature.
- There are two capacitors and three inductors in the two-stage HOM coupler. This results in two notch filter frequencies.
- The HOM coupler is superconducting, made of Nb. The overheating problem is avoided by using three inductors, which are connected to the superconducting outside conductor.

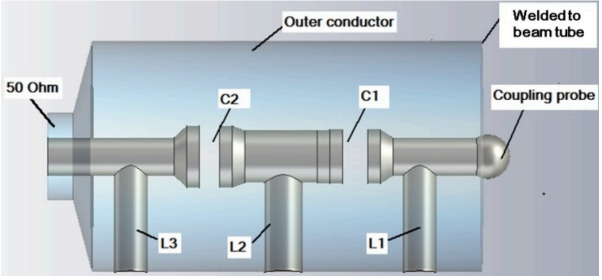

Figure 3: Schematic of the 2-stage HOM coupler.

The broadband transmission performance of the two-stage HOM coupler, simulated with CST Microwave Studio [10], is shown in Fig. 4. The are several improvements over the TESLA-type HOM coupler:

- There are two notch frequencies at 623 MHZ and 714 MHz, respectively. The S21 is smaller than -62 dB in this range. In addition, it is -73 dB at 703 MHz, and therefore the notch frequency shift is not a concern.
- The S21 at 817 MHz, the first higher order mode, is -23 dB. All other HOMs up to 3 GHz have larger S21, comparing favorably with the TESLA-type HOM coupler.

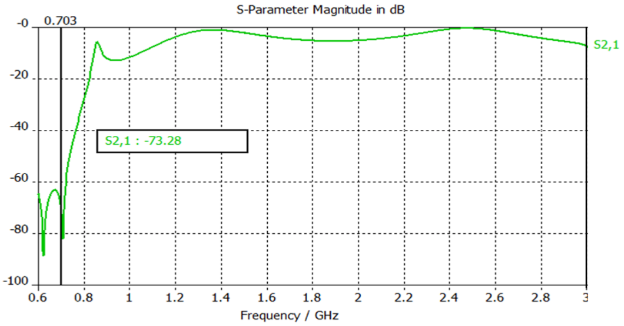

Figure 4: Performance of 2-stage HOM coupler.

Two-Stage HOM Coupler on Cavity

To assess effectiveness of HOM damping, we modeled an eRHIC cavity with two HOM couplers at each end. The couplers in each pair are azimuthally spaced by 120°. The pairs are rotationally offset by 60°, as shown in figure 5. The calculated external quality factors (Q_{ext}) of higher order modes are shown in Figure.6. Most HOMs have Q_{ext} below 10^4. While four modes with resonant frequencies around 1.6 GHz have external Q's above 10^4, their R/Q's are low, of the order of 0.1 Ohm. The final design will have three HOM couplers (spaced by 120°) at each end of the cavity and there will be 60° rotation between the coupler triplets in order to reduce power through each coupler.

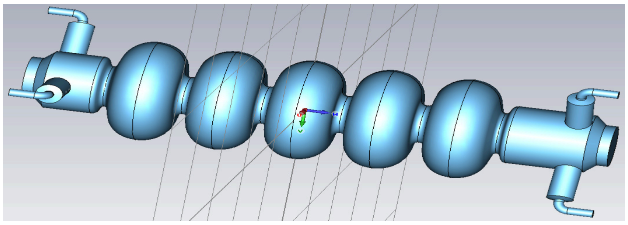

Figure 5: Cavity with 2-HOM couplers.

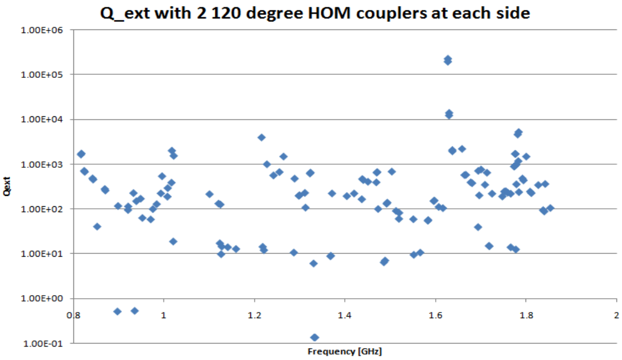

Figure 6: Qext of HOM spectrum.

Prototypes of the Two-Stage HOM Coupler

Copper prototypes of the two-stage HOM coupler were fabricated and shown in figure.7. We tested them with different pickup heads on a transmission line. One typical result from testing on the transmission line is shown in figure.8. As expected, it has good rejection of fundamental mode (<-63dB) and also good propagation of higher order modes (more than 30 dB higher than the fundamental mode.)

SUMMARY AND CONCLUSION

In order to damp HOMs in a high current ERL for eRHIC, a new HOM coupler has been designed. The simulations with two HOM couplers at each end of the cavity show that the HOM Qexts reach the requirement. The test of copper prototype shows that the designed HOM coupler performed as expected. The final design of the eRHIC cavity will have 3 HOM couplers at each end. A prototype copper cavity with removable beam pipes is expected to be completed by May, on which the HOM couplers will be tested.

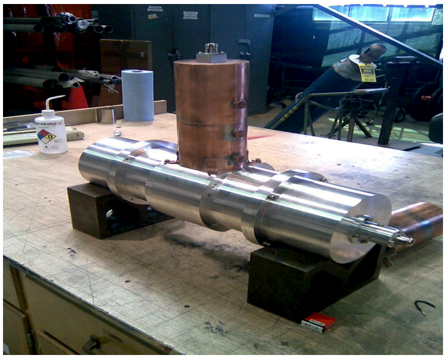

Figure 7: Cavity with 2-HOM couplers.

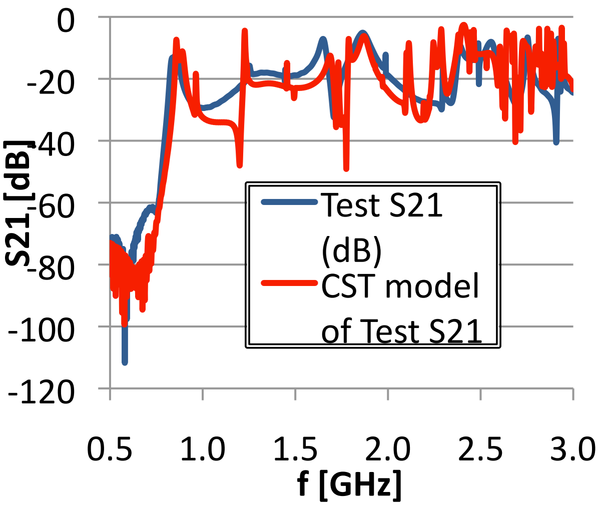

Figure 8: S21 from test and simulation.

REFERENCES

[1] http://www.bnl.gov/cad/eRHIC/erhic.asp
[2] V.N. Litvinenko et al, "High current energy recovery linac at BNL", Proceedings of FEL'04, 570-573
[3] H.Hahn et al, "Ferrite HOM Absorber for the RHIC ERL, http://www.bnl.gov/isd/documents/43583.pdf
[4] Wencan XU et al, NIM-A-662(2010), Pages 17-20
[5] Rama Calaga,, NIM-A 557 (2006)243-249C.
[6] Jacek Sekytowica,Higher order mode coupler for TESLA,Proceedings of 6th RF superconductivity
[7] TDR report of EXFEL, http://xfel.desy.de/tdr/tdr
[8] Sang-ho Kim, SNS superconducting Linac operational experience and upgrade path, LINAC08
[9] Rama, Calaga, phD thesis http://www.agsrhichome.bnl.gov/People/rcalaga/thesis.html
[10] CST, http://www.cst.com/