OVERVIEW OF RECENT HOM COUPLER DEVELOPMENT*

Binping Xiao†, Brookhaven National Laboratory, Upton, New York 11973-5000

Abstract

Higher Order Mode (HOM) damping is important for SRF applications, especially for high intensity machines. A good HOM damping design will help to reduce power load to the cryogenic system and to reduce the risk of beam breakup. The design of HOM damping, including antenna/loop HOM couplers, beam pipe HOM absorbers and waveguide HOM couplers, is to solve a multi-physics problem that involves RF, thermal, mechanical, and beam-cavity interaction issues.

In this talk, the author provides an overview on the latest advances of the HOM couplers for high intensity SRF applications.

INTRODUCTION

A charged particle bunch that encounters any cross-section perturbation of the beam pipe (SRF cavity in our case) can generate electromagnetic (EM) fields that might or might not get trapped within the perturbation. The EM fields will interact with, and influence the motion of this specific bunch and the following bunches. It can lead to beam quality degradation, beam energy loss, beam instability, and in the worst case, beam breakup. The EM fields can also interact with the SRF cavity and result in unwanted RF heating, multipacting etc. A good design of HOM damping would help to minimize the above-mentioned problems and allow higher beam intensity operation.

There are three major varieties of HOM couplers: beam pipe absorber, coaxial (loop/antenna) coupler and waveguide coupler. For high intensity application, it is possible that two, or even all three of these couplers to be adopted. This paper will cover the coaxial and waveguide couplers. For beam pipe absorbers, please refer to Eichhorn's talk [1].

The design of HOM damping is to solve a multi-physics problem that involves RF, thermal, mechanical, and beam-cavity interaction issues. Insufficient consideration on either aspect can lead to the failure of the SRF cavity operation. For example, for the 3.9 GHz FNAL/FLASH cavity, insufficient multipacting analysis of the fundamental mode in the HOM filter led to fracture of the coupler [2]; for the TESLA-shape loop HOM coupler, the RF loss on the tip of the HOM Nb antennae can give a limit to the accelerating gradient on CW operations[3-5]; for the 56 MHz Quarter Wave Resonator (QWR), the thermal quench caused by the brazing material at the sapphire-Nb joint limited the cavity performance to 330 kV in CW operation and 550 kV in pulsed operation [6].

In this paper, we will discuss the latest advances of the HOM coupler designs, the lessons learned and the approaches that were taken.

RECENT ADVANCES

DQW HOM Coupler

A Double Quarter Wave (DQW) crab cavity was designed for the Large Hadron Collider (LHC) luminosity upgrade [7]. A compact HOM filter with wide stop band at the deflecting mode is developed for this cavity, as shown in Figure 1 [8].

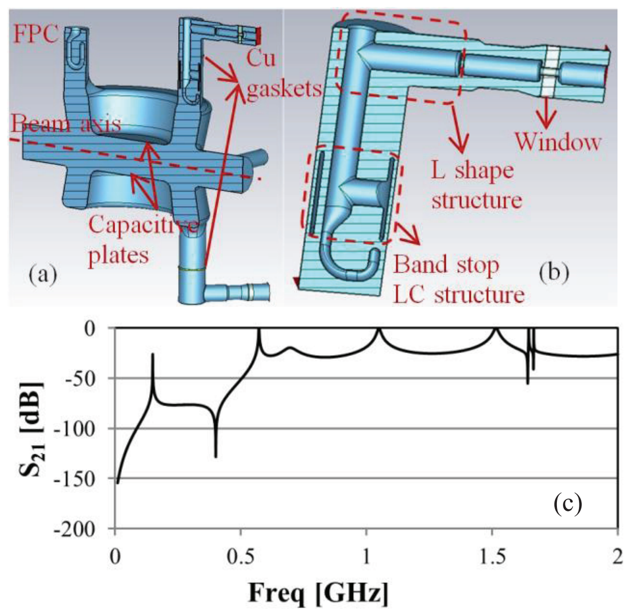

Figure 1: (a) DQW with 3 HOM filters; (b) HOM filter; (c) S_{21} of the HOM filter, with TE_{11} mode on the hook side and TEM mode on the port side. [8]

The HOM filter, shown in Figure 1(b), consists of a band stop LC structure right above the hook to minimize the RF loss on the Cu gasket that will be used to connect the cavity and the filter, shown in Figure 1(a), and an L shape structure on the top to form a pass band starting from 570 MHz, the frequency of the first HOM. There are three HOM filters in each cavity, with one on the FPC side with the pickup port along the beam pipe direction and the other two on the opposite side with the pickup port 60 degrees away from the beam pipe port. This symmetric design is adopted to lower the multipolar components of the fundamental mode field. The S_{21} of this design, with TE_{11} mode on the hook side and TEM mode on the port side, is shown in Figure 1(c). The

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†binping@bnl.gov

rejection at 400 MHz shows a 34 MHz stop band with S_{21} < -80 dB, and the minimum at -128 dB. However, the rejection for the first HOM at 570 MHz is only -2 dB.

RFD HOM Couplers

Besides DQW, an RF dipole (RFD) cavity was also designed for LHC luminosity upgrade by a SLAC and ODU joint effort. The lowest HOM frequency is more than 230 MHz above the operating mode. Waveguide HOM couplers were initially adopted [9] and were later changed to high-pass filter HOM couplers, following an advice from the committee members during the HiLumi-LHC/LARP crab cavity system external review meeting [10]. The current design [11] includes a hook coupler with high pass filter coupling to horizontal modes, and an *E*-probe coupling to vertical modes, as shown in Figure 2.

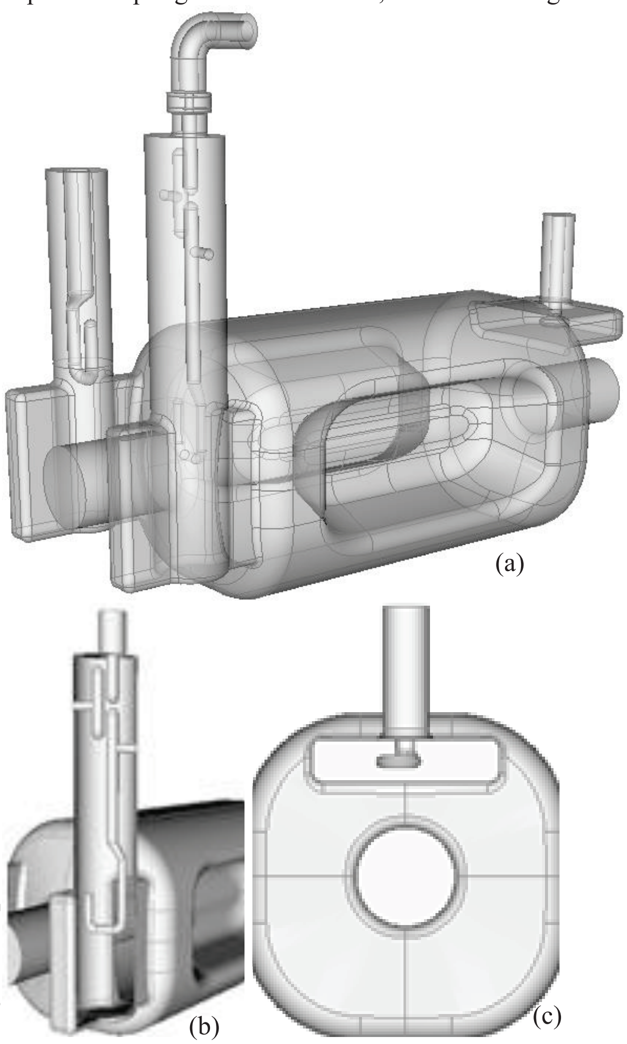

Figure 2: (a) RFD with all couplers; (b) Coupler for horizontal modes; (c) Coupler for vertical modes. [11]

56 MHz QWR HOM Coupler

The RHIC 56 MHz SRF cavity will provide a larger longitudinal acceptance for ion beams. Four HOM filters will be installed on the 56 MHz cavity. The filter locations are shown in yellow in Figure 3(a). The filter is designed as a two-stage Chebyshev T-type high-pass filter shown in Figure 3(b) [12]. During commissioning, the cavity voltage was limited by a quench in the HOM coupler assembly with maximum reached cavity voltage of 330 kV in CW operation and 550 kV in pulsed operation [6]. The HOM coupler has a sapphire RF window that is designed for separating the high-pass filter section from the cavity vacuum. The braze material at the sapphire-Nb cuff joint is InCuSil, which is normal conducting at 4.5 K. Thermal analysis shows that at 1/6th of the design field, the InCuSil material would bring the adjacent Nb (T_c = 9.2 K) to 8.5 K, eventually quenching the cavity. The filter was re-designed and construction of new HOM filters is currently on-going at JLab [13]. The re-design includes: (1) the removal of the sapphire window to eliminate the normal conducting braze material; (2) the adding of tuning bridge at the end of the filter stack to provide locking to the filter tuning position; and (3) the replacing of the Stycast® epoxy with Nb stoppers to eliminate outgassing in ultrahigh vacuum.

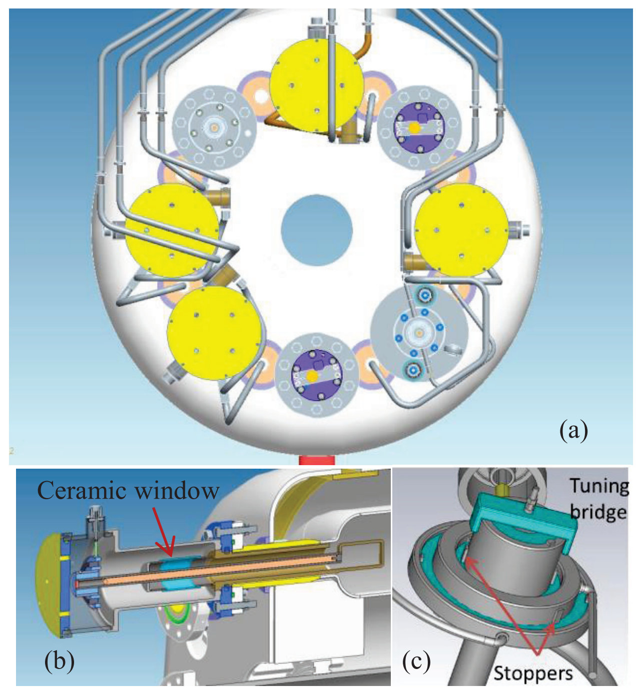

Figure 3: (a) Location of the HOM filters; (b) Original design of the HOM filter; (c) Illustration of the modifications. [13]

TESLA-shape HOM Couplers

The TESLA-shape F-key HOM coupler is a mature design, with more than a hundred being operated up to 35 MV/m for many years in TTF and around the world in short pulse mode (a few percent duty factor) with beam current up to 10 mA [3]. For CW operation, however, an insufficient heat conduction of the ceramic window on HOM feedthroughs, either using alumina or using sapphire, causes heating of the Nb antenna above its T_c, and thus limits the cavity operation in the range of 5 and 14 MV/m. JLab, DESY and KEK modified the coupler design [3-5] by trimming the shape of the HOM antenna,

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and using material with better thermal conductivity. With these modifications, the cavity can easily achieve 20 MV/m with less than 200 mK temperature increase on the HOM antenna tip [5].

BESSY-VSR HOM Coupler

The BESSY VSR project is a future upgrade of the 3[rd] generation BESSY II light source. 15 ps long bunches and 1.5 ps short bunches will be stored simultaneously in the 1.5 GHz cavities. These cavities will operate in CW at high field levels (E_{acc} = 20 MV/m) with high beam current (I_b = 300 mA), which makes the HOM damping really challenging [14]. Current design with five waveguide couplers and one coaxial coupler on the enlarged beam pipes near end cells offers the capability to handle high power while providing very high damping levels. The HOM damping scheme is shown in Figure 4. One of the waveguide coupler will be replaced by an FPC coupler, with the damping level slightly reduced [14].

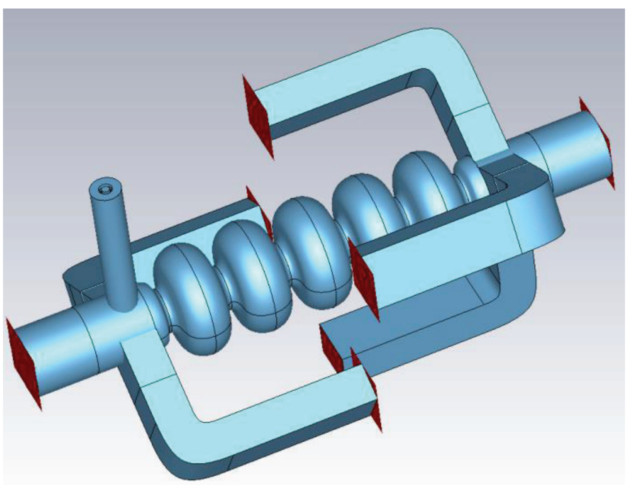

Figure 4: 5-cell 1.5 GHz BESSY-VSR cavity with five waveguide couplers and one coaxial coupler.

eRHIC HOM Couplers

HOM damping of the eRHIC accelerating cavities is an extremely challenging problem due to the high current, high bunch charge, multi-pass CW operation, with a total 7.3 kW HOM power per 5-cell cavity. A combination of coaxial coupler [15], waveguide coupler [16] and beam-pipe absorber [17] is going to be used. The configuration and simulation/test S21 curves for both coaxial and waveguide couplers are shown in Figure 5. Besides the above mentioned couplers, beam pipe absorber will also be used.

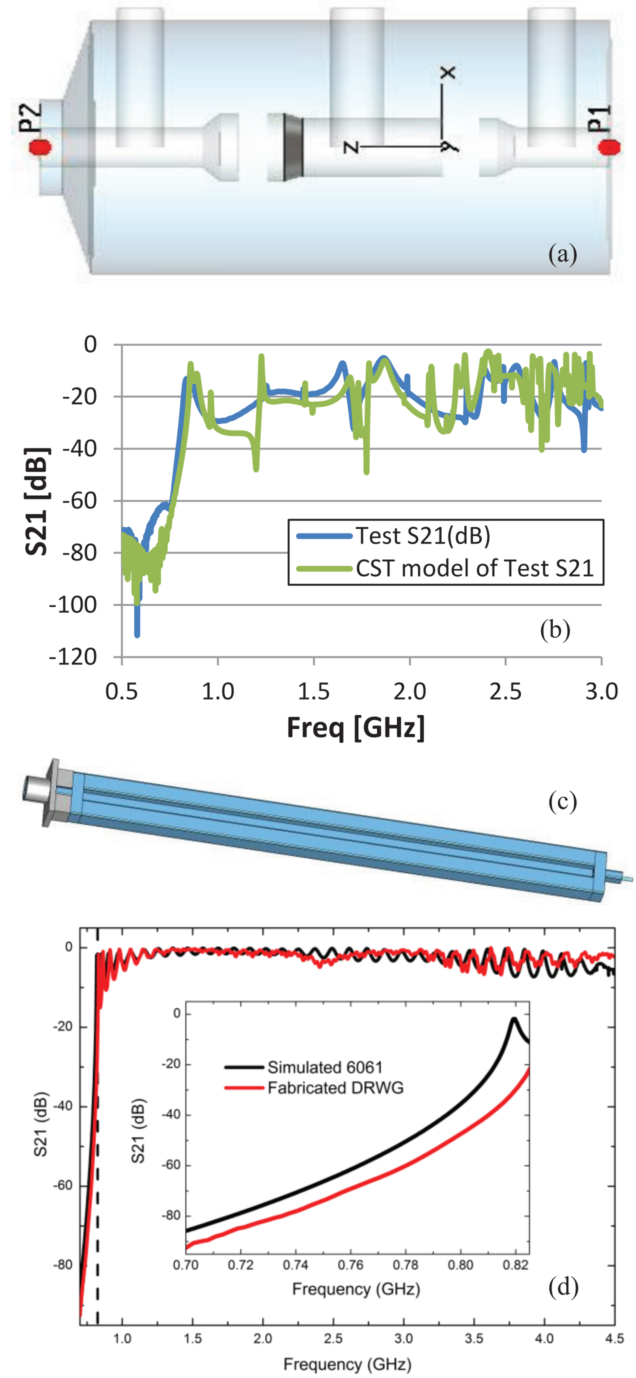

Figure 5: (a) Two-stage coaxial coupler with (b) simulated and tested S21 and (c) double ridged waveguide coupler with (d) simulated and tested S21.

MEIC HOM Couplers

For MEIC, the first SRF cavity design will be a 952.6 MHz single cell on the ion ring, with the possibility to expand it to a two-cell design, and for the electron ring it will be a single cell. The on-cell damping, shown in Figure 6(a), is optimized with a number of on-cell waveguides, their size and location on the transverse impedance [18]. For the MEIC electron cooler cavity, "T" shape waveguide HOM coupler with a stub, shown in

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Figure 6(b), is suggested, with one on each side of the cavity that are perpendicular to each other to couple both vertical and horizontal modes. With modified waveguide width, it can allow both TE10 and TE20 modes propagate in order to damp both polarization of HOMs. This simple design works perfectly for low HOM power, or low beam current that is less than 20 mA [19].

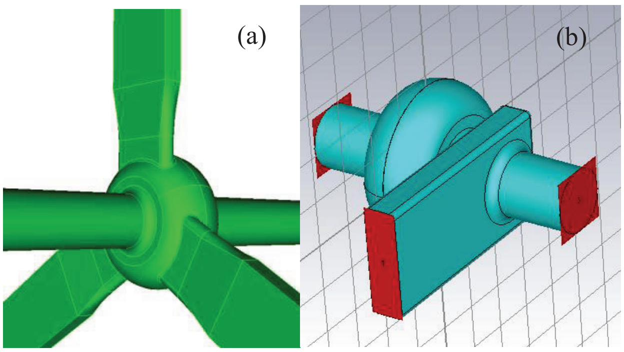

Figure 6: (a) On-cell damping of the 952.6 MHz single cell cavity for MEIC; (b) "T" waveguide with a stub for the MEIC electron cooler cavity.

New Ideas

A good design of the HOM filter can effectively conduct out the HOM power generated in the cavity by the beam passing through. To reduce the amount of HOM power in the cavity, optimization of the cavity shape is needed. For enlarged beam pipe with taper connected to the end cell of the cavity, the detailed geometry of this transition should be optimized to balance the loss factor and the fundamental R/Q of the cavity [14, 20]. The Photonic Band Gap (PBG) cavity [21], and the cage cavity [22], are great idea on suppressing and damping the HOM modes in a cavity.

The idea to use a C-Shape Waveguide (CSW) [23], which can be seen as a deformed coaxial line, or a deformed ridged waveguide, is a high pass filter by its nature. Comparing to ridged waveguide, the size of the CSW is even more compact, thus the static loss is smaller if the same length is used. Comparing to coaxial line, the shape of the CSW makes its inner conductor easier to be cooled and makes it easy to transit into a coaxial line.

CONCLUSIONS

In this paper, the recent advances of the HOM coupler designs are reviewed. Coaxial coupler designs on DQW and RFD crab cavities, and on QWR 56 MHz cavity are introduced; Waveguide coupler designs on MEIC 952.6 MHz single cell cavity, on MEIC electron cooler cavity, and on BESSY-VSR cavity are described. A combination of coaxial coupler, waveguide coupler and beam pipe absorber will be used on the eRHIC SRF cavity.

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