HOM DAMPER HARDWARE CONSIDERATIONS FOR FUTURE ENERGY FRONTIER CIRCULAR COLLIDERS*

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Abstract

Future high luminosity energy frontier e^+e^- circular colliders CEPC and FCC-ee will operate with high average beam currents. Radio-frequency systems in these machines utilize superconducting RF (SRF) structures with strong damping of higher order modes (HOMs). In this paper I will consider HOM damping options for the colliders under consideration, review HOM damper hardware, both existing and under development, and outline R&D necessary to develop efficient HOM damping in the future circular colliders.

INTRODUCTION

Superconducting RF systems of the future energy frontier e^+e^- circular collider CEPC and FCC-ee will have to deal with high average current particle beams consisting of a large number of short bunches [1]. The machines will be very big with a circumference between 50 and 100 km. As a result, the beams will have very wideband spectra with densely spaced frequency lines. Therefore HOM damping schemes for future colliders are quite challenging. Any selected scheme will have to be capable of handling kilowatts of HOM power via a combination of HOM couplers and beam pipe absorbers, see [2], for example. The latter are required to intersect the high-frequency part of HOM power, which propagate through the beam pipes. Typically required loaded quality factors of HOMs are in the 10^2 to 10^4 range. In this paper I review HOM dampers, existing and under development, with an emphasis on their applicability to the future energy frontier circular colliders.

COUPLER TYPES

There are a large variety of HOM damper designs for SRF cavities, many of them reviewed in references [3]-[4]. However, very few of those dampers are designed to handle high average HOM power and even fewer demonstrated this in operation. The three main HOM damper configurations are based on different transmission lines and coupling circuits. These are: beam pipe absorbers, rectangular waveguide HOM couplers and loop/antenna HOM couplers to a coaxial line [4]. In this section we discuss pros and cons of different HOM damper types and consider existing designs.

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Beam Pipe Absorbers

The beam pipe absorbers (HOM loads) are arguably the most efficient in HOM damping and will be required to absorb the high frequency part of HOM power, which propagates along the beam pipe. The absorber is a section of beam pipe with its inner surface covered by a layer of microwave-absorbing material, e.g. lossy ferrite or ceramics. Drawbacks of the beam pipe absorbers are: i) most absorber materials are brittle, can create particulates that contaminate SRF cavities; ii) parasitic beam-absorber interaction is significant and contributes to the overall HOM power; iii) the main disadvantage for large SRF systems is that the HOM loads occupy real estate along the beam axis and thus reduce the SRF system fill factor.

Room temperature HOM loads were originally developed at Cornell University and KEK for very high average power HOM absorption in the high-current e^+e^- colliders CESR and KEKB [5]-[6]. These HOM loads utilize lossy ferrite materials and demonstrated capacity to absorb several kilowatts of HOM power in operation: 2.9 kW per load at CESR and 8 kW per load at KEKB. In both cases the loads were used in conjunction with single cell SRF cavities as illustrated in Figure 1.

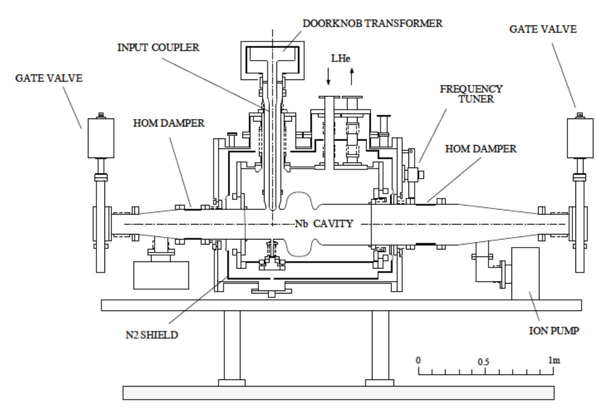

Figure 1: Single cell KEKB SRF cavity with beam pipe HOM dampers [7].

The CESR HOM loads, as the one shown in Figure 2, are used in many high-current storage rings around the world as well as in the R&D ERL at BNL [8]. The KEKB loads are installed in BEPC-II and are planned to be used at SuperKEKB, where the HOM power is expected to reach 15 kW per absorber.

The beam pipe absorbers operating at cryogenic temperatures have dissipation capacity of ~100 W [4] and are not suitable for the future circular colliders.

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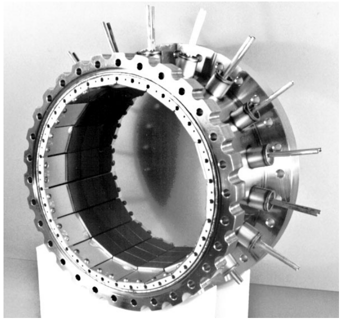

Figure 2: CESR-type HOM load [5].

Rectangular Waveguide Couplers

The waveguide couplers can provide very efficient damping in a broad frequency range and don't compromise the fill factor. In theory, these couplers should be able to handle high HOM power, but it has not been demonstrated in operation yet. The main disadvantage of using waveguides is that their large size complicates the cavity and cryomodule designs.

This damping scheme is worked on at Jefferson Lab primarily in the context of developing SRF structures for high-current ERLs and for the electron-ion collider MEIC. For multi-cell cavities, the waveguides are configured in a Y-shape on each of the cavity's beam pipes as shown in Figure 3. The waveguides are then routed through the cryomodule and terminated with water-cooled loads at room temperature either outside or inside the vacuum vessel as illustrated in Figure 4.

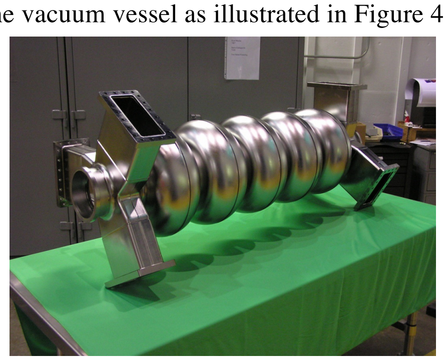

Figure 3: 750 MHz ERL cavity (courtesy of JLab).

Coaxial Antenna/Loop Couplers

The coaxial loop/antenna HOM couplers can provide strong HOM damping, but they require means of rejecting the fundamental mode. Rejection filters are typically very narrowband and must be carefully tuned. Also, these couplers are more difficult to cool than two other types.

First couplers of this type were developed for HERA and LEP. Later on, experience with LEP couplers was used to design couplers for SOLEIL, LHC, and Super-3HC cryomodules at SLS and ELETTRA. In addition to the LEP2 dipole mode coupler, the LHC SRF cavities have broadband couplers. The LHC couplers, depicted in Figure 5, were designed for ~1 kW HOM power level, but operate at lower HOM power levels so far.

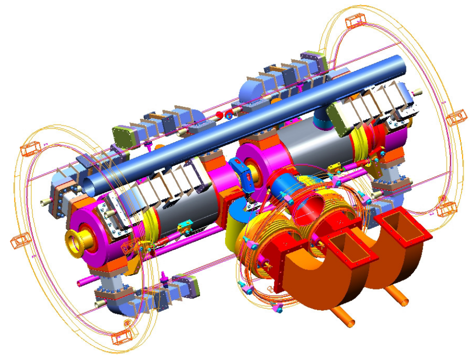

Figure 4: The cryomodule concept with rectangular waveguide HOM couplers (courtesy of JLab).

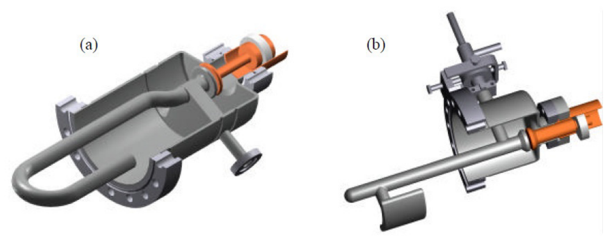

Figure 5: LHC HOM couplers: (a) narrow band dipole; (b) broadband [9].

HOM COUPLERS UNDER DEVELOPMENT

Several new designs, that might be suitable for the future circular colliders, are under development. Here we consider design efforts at JLab and BNL.

For single cell cavities, JLab is developing an "on-cell" waveguide damper scheme, which allows satisfying very stringent HOM damping requirements of MEIC. A concept of such cavity is shown in Figure 6.

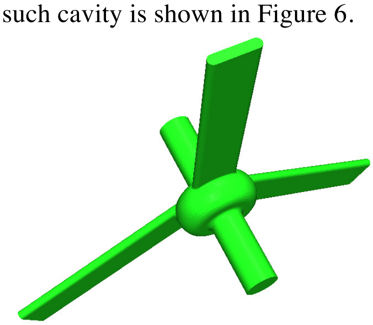

Figure 6: A concept MEIC cavity with an "on-cell" waveguide HOM damping (courtesy of JLab).

To avoid difficulties associated with the narrowband rejection filters in coaxial couplers, one can use high-pass filters. The high-pass filters, if properly designed, should be easy to tune and should have relaxed fabrication tolerances. BNL is developing several new designs capable of transmitting ~1 kW of HOM power.

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A couple of designs are under development for the 704 MHz five-cell BNL3 cavity [10, 11]. One of the designs utilizes a two-stage Nb band-stop filter [12], shown in Figure 7. Three such couplers will be connected to the BNL3 cavity at each beam pipe for an efficient HOM damping.

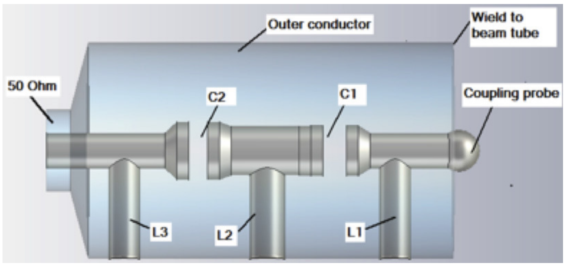

Figure 7: Two-stage band-stop filter [12].

The second design uses a dual ridge waveguide as a natural high-pass filter. A dual ridge waveguide provides a compact cross-section as compared to a rectangular waveguide. The most critical component in this layout is an antenna-to-waveguide transition. A broadband transition, shown in Figure 8, was designed and modeled. It has RF performance better than that of the two-stage coupler design, as illustrated by Figure 9 [13]. However, at this moment it is not clear, which design would be i) easier to fabricate and ii) less prone to multipacting.

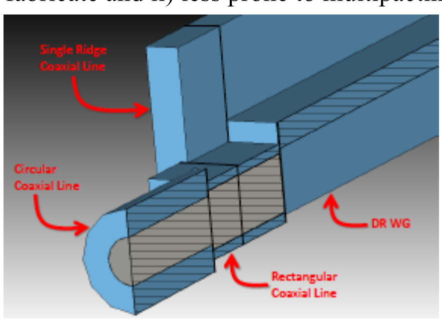

Figure 8: Layout of the broadband coaxial line to dual ridge waveguide transition [13].

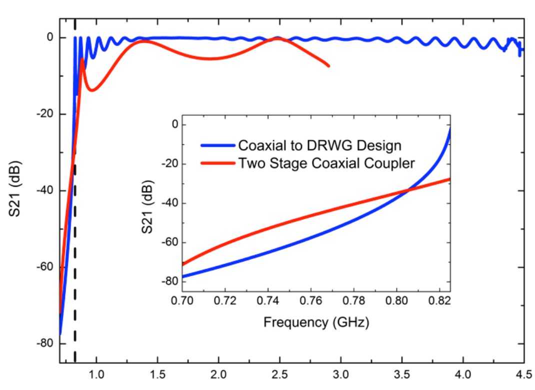

Figure 9: Comparison of the dual ridge waveguide and two-stage filters. The inset shows data from the fundamental mode to the first HOM [13].

Yet another high power HOM filter design, which might be suitable for the future colliders, is being worked on for the HL-LHC compact double quarter wave crab cavity [14]. The filter layout [15] is shown in Figure 10.

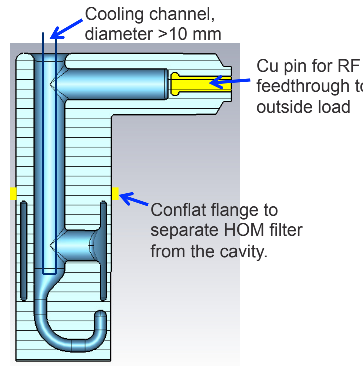

Figure 10: HOM coupler of the double quarter wave crab cavity for HL-LHC.

SUMMARY

There are many proven designs of HOM dampers. However, only beam pipe absorbers demonstrated so far performance level of interest for CEPC and FCC-ee. The LHC HOM couplers were designed for ~1 kW HOM power levels, but operate at lower HOM power levels thus far. There are several promising new designs under development, which might be suitable for future circular colliders.

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