HOM SIMULATIONS AND DAMPING SCHEME FOR CEPC CAVITIES

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Abstract

In this paper, it will be presented that the higher order mode (HOM) analysis of the 650 MHz cavities for the Circular Electron-Positron Collider (CEPC). The higher order modes excited by the intense beam bunches must be damped to avoid additional cryogenic loss and multi-bunch instabilities. To keep the beam stable, the impedance budget and the HOM damping requirement are given. The conventional coaxial HOM coupler, which will be mounted on the beam pipe, is planned to extract the HOM power below the cut-off frequency of the beam pipe, and the propagating modes will be absorbed by the two HOM absorbers at room temperature outside the cryomodule.

INTRODUCTION

With the discovery of the Higgs boson at the LHC in 2012, the world's high energy physics (HEP) community is interested in future large circular colliders to study the Higgs boson. Because the Higgs mass is low (126 GeV), a circular e+e- collider can serve as a Higgs factory. The Institute of High Energy Physics (IHEP) in Beijing, in collaboration with a number of other institutes, has launched a study of a 50-100 km ring collider [1]. It will serve as an e+e- collider for a Higgs factory with the name of Circular Electron-Positron Collider (CEPC). A Preliminary Conceptual Design Report (Pre-CDR) was published in March, 2015 [2]. The e+e- beams are in the same beam pipe with a pretzel orbit, which is not suitable for a high luminosity Z factory. To solve the problem, a double ring scheme was raised, and the machine circumference was increased to 100 km [3]. The baseline SRF system layout and parameters (Table 1) are chosen to meet the minimum luminosity requirement for each operating energy, and with possible higher luminosity [4].

DAMPING REQUIREMENT

The baseline of the collider is a double-ring with 650 MHz 2-cell cavities shared between the two collider rings [4, 5]. In a storage ring, the beam instabilities in both the longitudinal and transverse directions caused by the RF system are mainly from the cavities themselves. To keep the beam stable, the radiation damping time should be less than the rise time of the multi-bunch instability. The HOMs of the cavities must be damped sufficiently to prevent coupled bunch instabilities and to limit parasitic mode losses. To damp different polarization HOMs, at least two HOM couplers per cavity are needed. The couplers need to damp the HOMs at frequencies from 780 MHz to1471 MHz as shown in Figure 1.

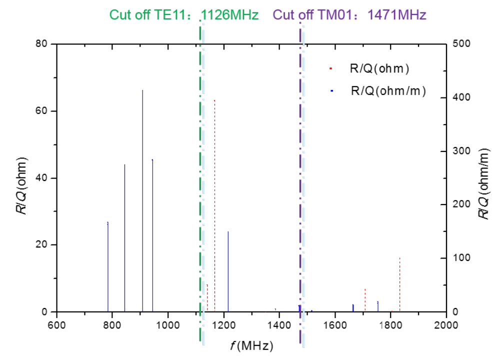

Figure 1: 650 MHz 2-cell cavity mode spectrum and the beam pipe cut-off frequency.

Table 1: Collider Superconducting RF System Parameters (100 km DR)

parameter	H	Z
Luminosity [10^{34}cm^{-2}s^{-1}]	2	12
Energy [GeV]	120	45
SR power/beam [MW]	32	16
RF voltage [GV]	2.1	0.14
RF frequency [MHz]	650	650
Beam current [mA]	19.2	466
Bunch length [mm]	2.9	4.0
Bunch charge [nC]	15.5	7.3
Cavity number in use / beam	336	48
Gradient [MV/m]	14	6.3
Input power / cavity [kW]	190	335
HOM power / cavity [kW]	0.4	1.8

The average power losses can be calculated as single pass excitation. As shown in Figure 2, HOM power damping of 0.47 kW for each 650 MHz 2-cell cavity is required for the CEPC collider. Resonant excitation should be considered especially for the low frequency modes below cut-off. The cut-off frequency of the waveguide modes for the beam pipe are 1.471 GHz (TM01) and 1.126 GHz (TE11). All the HOM power below the cut-off frequency should be coupled by the HOM coupler which mounted on the beam pipe and the propagating modes will be absorbed by the two HOM absorbers at room temperature outside the cryomodule.

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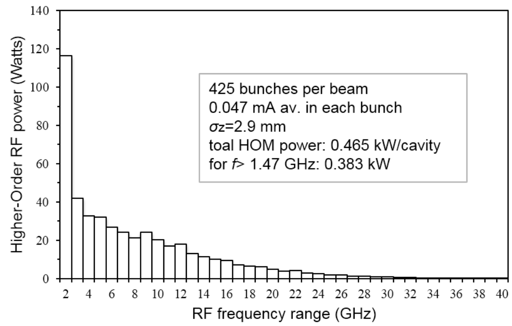

Figure 2: Frequency distribution of HOM power (H design).

HOM COUPLER DESIGN SCHEME

The HOM coupler design must be optimized for the operating frequency (high damping) and the HOM spectrum (low damping) of the cavities. A loop type HOM coupler is given by the transmission line models [6]. Figure 3 shows the equivalent circuit used for the coupler design. Capacities and inductances are determined with respect to the HOM spectrum. Although single notch design is easier to fabrication, it is more sensitive and difficult to tuning the fundamental mode. Compared with single notch coupler, a double notch coupler is chose because of its large bandwidth for the fundmental mode (see Figure 4). M is the inductance of the cylinder-shaped mechanical support of the inner conductor of the coupler. It also provides a convenient path for helium into the coupler to cool the inner part of the coupler. Transmission behavior optimized according to the HOM spectrum of the cavity by adjusting all design parameters.

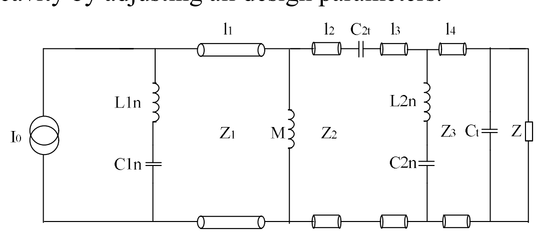

Figure 3: Transmission line equivalent circuit.

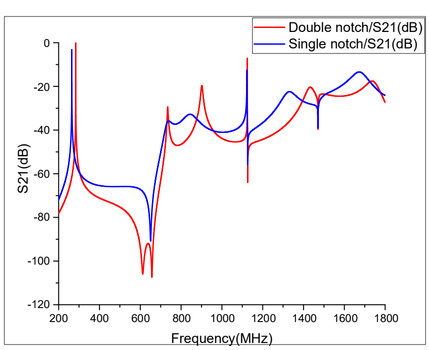

Figure 4: S_{21} of single notch coupler and double notch coupler.

The 3D model is optimized by simulations with CST MWS [7]. The beam tube with HOM coupler model was used for analyzing the transmission characteristics. Both sides of the tube terminated with a waveguide port, excites monopole as well as dipole modes, whereas the coaxial output port excites the TEM mode. The results for the preliminary optimization of the coupler are shown in Figure 5.

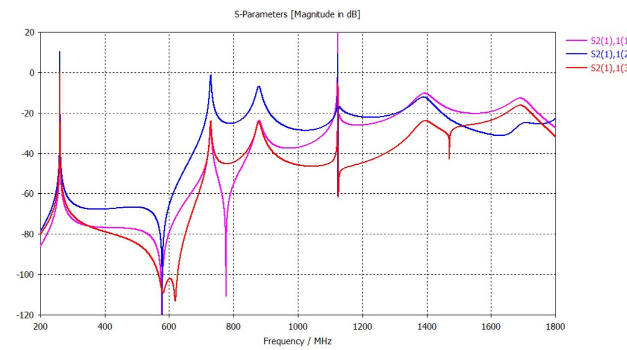

Figure 5: S_{21} of the couplers ($S2(1),1(1)$ & $S2(1),1(2)$ represents TE11-TEM transmission, $S2(1),1(3)$ represents TM01-TEM transmission).

The damped Q values are calculated for a 2-cell cavity equipped with two loop HOM couplers. The angle between two couplers is 120 degree, as shown in Figure 6. The damping results compared with the impedance thresholds are shown in Figures 7 and 8. The feedback time is chose 3.3 ms when we give the impedance thresholds. As can be seen from the results, the damping for all the monopole modes and dipole modes of the design are below the H-pole impedance thresholds. The Q_e for the TM011 mode cannot meet the requirement for operating at the Z-pole. It should be noted that we didn't take into account the spread in the resonance frequencies of different cavities. If the frequency spread is 0.5 MHz, the impedance threshold can increase 1~2 orders of magnitude [5].

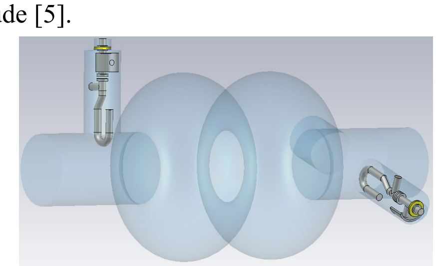

Figure 6: 2-cell cavity with 2 loop HOM couplers.

HOM ABSORBER DESIGN SCHEME

The HOM absorber is mainly used to damp the HOM power above 1.4 GHz. The structure of the HOM absorber is similar to a circular waveguide. Then the microwave absorbing material will be brazed onto the inner surface of the waveguide. Due to the high Q_e threshold of HOM above 1.4 GHz, which is 10^6 or larger, one or two types of absorbing material will be adequate for the wide frequency range.

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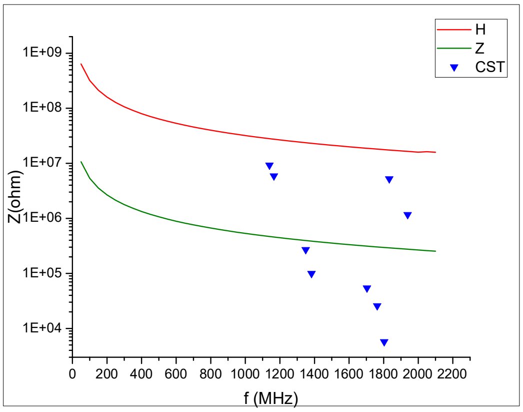

Figure 7: Monopole modes damping results compared with impedance threshold.

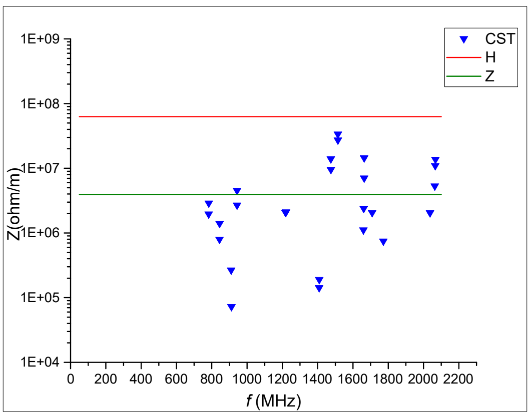

Figure 8: Dipole modes damping results compared with impedance threshold.

The size of the waveguide of the absorber is the same with the beam pipe of the 650 MHz cavity. According to experience at BEPC-II, in the initial design the ferrite is used to absorb the HOM power. The RF model of the HOM absorber is shown in the Figure 9. The ferrite shape is cut into a rectangular brick. This will reduce the fabrication cost dramatically and will also lessen the difficulty in ferrite machining and brazing. For further higher damping requirement, this structure makes it feasible to mount different kinds of absorbing material to fulfill broad band operation.

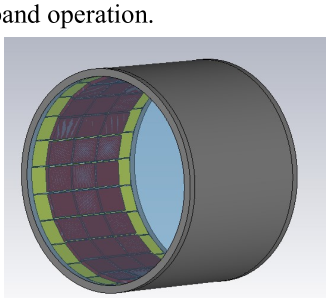

Figure 9: RF model of HOM absorber.

The absorber will damp about 3 kW HOM power, so the absorber cannot be placed in the cryomodule. The absorber temperature will rise, so the ferrite must be water cooled. Effective cooling for each ferrite brick is accomplished with the cooling structure shown in Figure 10. At this stage in the mechanical design, there is a balance between structure complexity and cooling efficiency. Further simulation and optimization of the mechanical design will be performance in the future.

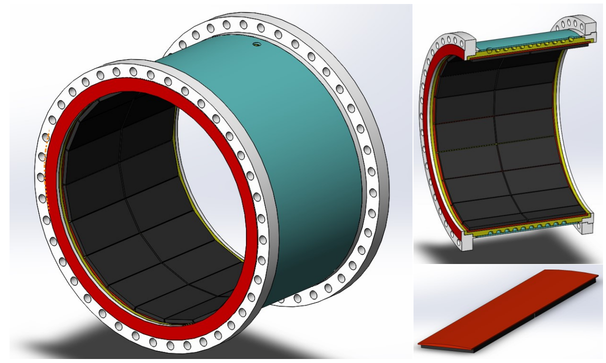

Figure 10: Cooling structure of ferrite (right) and first mechanical design of absorber (left).

CONCLUSIONS

In this paper, we give a reasonable HOM coupler and absorber design for CEPC. The frequency distribution of the HOM power shows that the total HOM power for each cavity is 0.47 kW.

A double notch HOM coupler is designed with respect to the transmission line model. After the double notch HOM coupler introduced to the cavity, almost all the HOMs are under the impedance thresholds.

In the initial design the ferrite is used to absorb the HOM power above the cut off frequency. The RF model as well as the cooling structure of the HOM absorber are given.

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