ISBN: 978-3-95450-211-0 doi:10.18429/JACoW-SRF2019-THP070

CEPC HOM COUPLER R & D *

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Abstract

The Circular Electron Positron Collider (CEPC) will use a 650 MHz RF system with 240 2-cell cavities for the collider. To keep the beam stable and avoid additional cryogenic loss, a double notch coupler is chosen due to its wide bandwidth for the fundamental mode. In this paper, the CDR design and prototyping of the higher order mode (HOM) coupler for the collider ring will be introduced. Low power test of the HOM coupler has been accomplished by a coaxial line test bench. The high power test has been also carried out in room temperature.

INTRODUCTION

CEPC is a proposed 100 km circular electron-positron collider operating at 90-240 GeV center-of-mass energy of Z, W and Higgs bosons. The luminosity goal for Higgs is 2×10^{-34} cm^{-2} s^{-1} and higher than 1×10^{-34} cm^{-2} s^{-1} for Z-pole. The conceptual design report (CDR) of CEPC has been published in August, 2018 [1]. CEPC parameters and lattice design for the collider are described in the CDR. CEPC will use a 650 MHz RF system with 240 cavities for the Collider and a 1300 MHz RF system with 96 cavities for the Booster. The collider is a double-ring with shared cavities for Higgs operation and separate cavities for W and Z operations as shown in Fig. 1. This common cavity scheme will reduce the total cavity and cryomodule number as well as the cryogenics by half compared to the usual double ring with separate cavities for the two rings. The electron or positron beams will go through the two RF stations in each RF section for Higgs operation. When operating for W and Z, part of the Higgs cavities will be used in each RF section, and the electron or positron beams will go through only one of the two RF stations of a RF section.

Higher-order-modes excited by the intense beam bunches must be damped to avoid additional cryogenic loss and beam instabilities. This is accomplished by extracting the stored energy via coaxial HOM couplers mounted on both sides of the cavity beam pipe. The HOM absorbers are outside the cryomodule. From LEP2 and LHC experience of handling large higher-order-mode power in a multi-cavity cryomodule with coaxial HOM couplers [2] [3], the upper-limit of average HOM power produced in each 2-cell 650 MHz cavity is set to be 2 kW. Each cavity has two detachable coaxial HOM couplers mounted on the cavity beam pipe with HOM power handling capacity of 1 kW.

The RF design, tolerance analysis, thermal analysis as well as mechanical structures of the HOM coupler have been finished [4]. This study focuses on the HOM coupler fabrication and tests; the remainder of the paper is organized as follows: Sec. II introduces the fabrication status of the HOM couplers for room temperature test and low temperature test. A coaxial test bench has been designed and fabricated for HOM coupler test, which is presented in Sec. III along with the test results for the test bench. In Sec. IV, the low power test results of the HOM coupler are given. The high power test results and plans are listed in Sec. V. Finally, the conclusions are summarized in the last section.

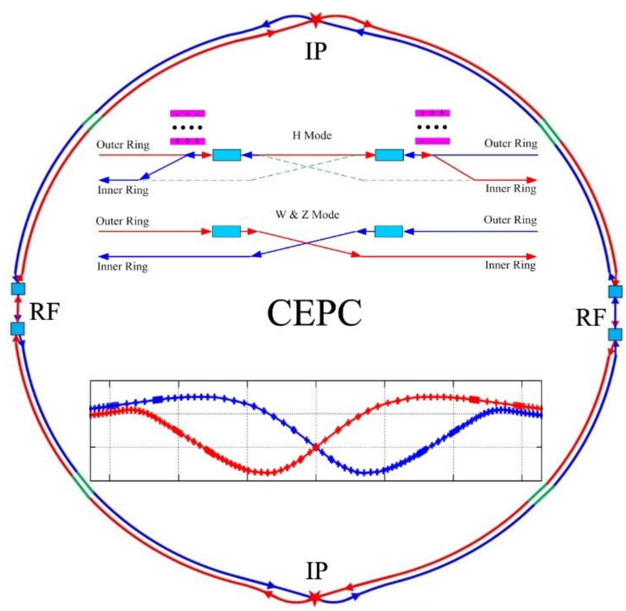

Figure 1: Layout of CEPC collider.

HOM COUPLER FABRICATION

A test cryomodule with two 650 MHz 2-cell cavities is in fabrication and will be assembled in the test cryomodule in 2019 [5]. The cavity will be equipped with HOM couplers and other accessories which will form a completed crymodule. Beam test with a DC photo cathode gun (CW 10 mA) is scheduled to start in 2020 at a new SRF laboratory in the Platform of Advanced Photon Source Technology R&D (PAPS) [6]. To check the HOM coupler performances at room temperature, two dismountable HOM couplers with different inner conductor length were fabricated. Four formal prototypes have been processed and are awaiting for the low temperature test.

* Work supported by National Key Programme for S&T Research and Development (Grant NO.: 2016YFA0400400) and Xie Jialin Funding.
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Prototype Fabrication for Room Temperature Test

Two stainless steel prototypes of HOM coupler were fabricated for the measurement of the transmission characteristics. The inner conductor of each HOM coupler was designed with different length as shown in Fig. 2 to find the impact on the transmission properties. To ensure the installation accuracy of the different parts of the HOM coupler, a fixture was designed. The different parts of the HOM coupler, the prototypes and the fixture used for installation are shown in Fig. 3.

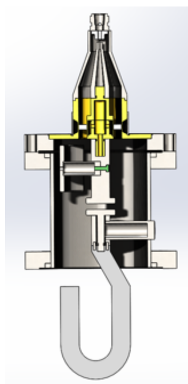
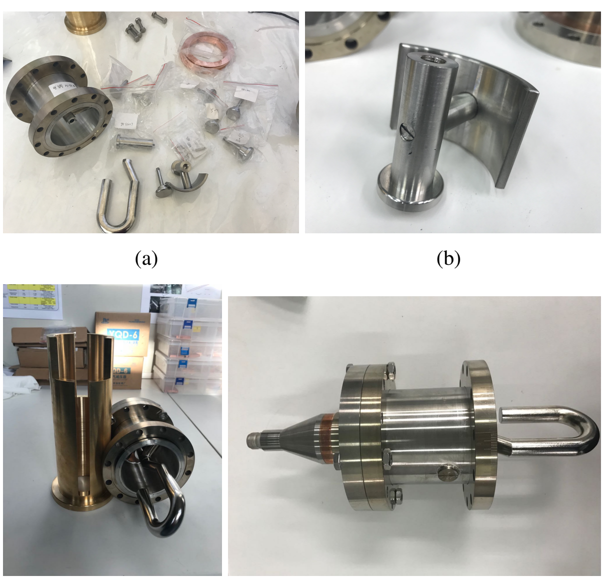


Figure 2: Dismountable HOM coupler model.



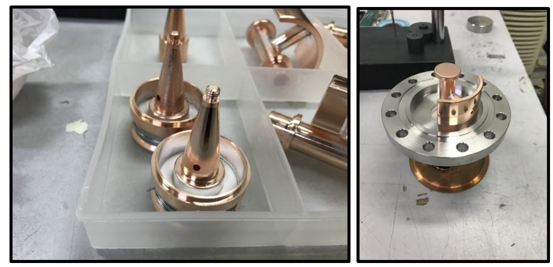
(a) (b)

(c) (d)

Figure 3: (a) Detachable parts, (b) T type inner conductor, (c) the fixture used for installation, (d) HOM coupler prototype.

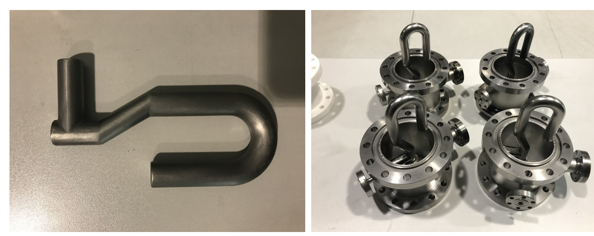
Prototype Fabrication for Low Temperature Test

The fabrication of the formal HOM coupler prototypes used for the CEPC collider test cryomodule with two 650 MHz 2-cell cavities have been completed. The detachable HOM coupler is composed of two parts, one part includes a niobium loop, a niobium shell, two flanges and a helium jacket made of Nb55Ti, the other part includes a ceramic window, a copper probe and a stainless steel flange. Four HOM couplers are already made by two different companies. Fig. 4 shows the ceramic window and the whole upper part of the HOM coupler. Fig. 5 shows the loop part and the whole bottom part of the HOM coupler with helium jacket. Post-processing has been done for the bottom part, with BCP 100 μm, and baking at 750 °C.



(a) (b)

Figure 4: (a) The ceramic window, (b) the upper part of the HOM coupler .



(a) (b)

Figure 5: (a) The loop part, (b) the bottom part of the HOM coupler with helium jacket.

TEST BENCH FABRICATION

To characterize the transmission and reflection of the HOM coupler and check the influence of the fabrication errors, a coaxial transmission line was used to measure the transmission properties of the coupler.

Test Bench Design

The stainless steel coaxial transmission line includes two standard N type connectors, a transition part with conical shape and a HOM coupler connector. Two Teflon sheets with flower structure has been designed in order to support the inner conductor and reduce the reflection of the coaxial line as shown in Fig. 6. The geometry of the coaxial line has been optimized to reduce the voltage standing wave ratio (VSWR) to meet the requirements for the measurement of the HOM transmission characteristics.

Test Bench Test

The coaxial transmission line has been developed as shown in Fig. 7. The reflection properties of the coaxial transmission line has been measured by the vector network analyzer (Rohde&Schwarz). Fig. 8 shows the measured

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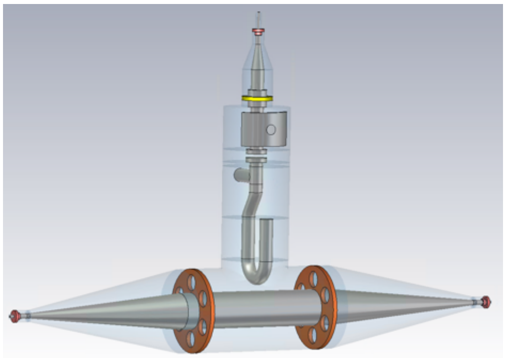

Figure 6: The coaxial transimission line with HOM coupler model.

results of the reflection coefficient compared with the simulation results. As we can see, the measured results agree well with the simulated results after consider the machining tolerances.

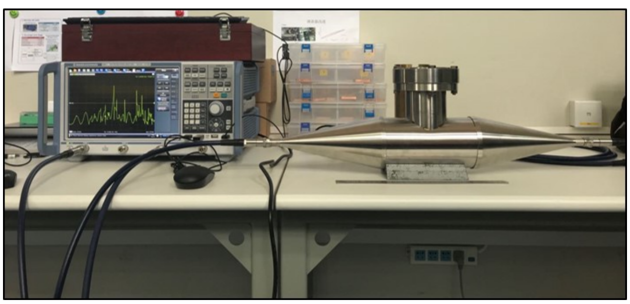

Figure 7: The coaxial transmission line prototype.

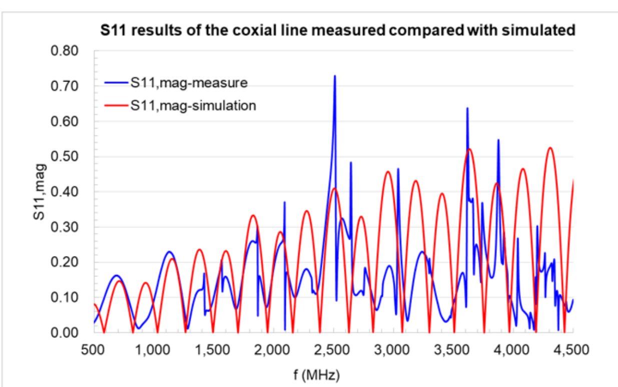

Figure 8: The reflection properties of the coaxial line prototype measured compared with simulated.

HOM COUPLER LOW POWER TEST

With the vector network analyzer, the transmission characteristics of the HOM coupler has been measured with the coaxial transmission line prototype. Feed-in the signal from the coaxial transmission line named port1, pick up the signal from HOM coupler port named port2 and the third port is connected with a matched load as shown in Fig. 9. The measured S21 parameters compared with simulated results are shown in Fig. 10. The S21 parameter measured is -90.5 dB for the first notch and -74 dB for the second notch, which indicates the HOM coupler is a good notch filter at working point. The bandwidth of the notch frequency measured for the notch filter is about 101 MHz, which is wide enough that the HOM coupler need not to be tuned in practice. It can be seen from Fig. 10 that the measured S21 values are larger than the simulated values, and the bandwidth of the notch frequency measured is also wider than the simulated results. The first reason for the differences is to take a different number of sample points. The number of result data samples used for simulation is 50001, while is only 30001 for test which is limited by the vector network analyzer used. The less data samples mean that it's possible to miss the minimum point. The second reason for the difference is mainly from the fabrication and assembly errors. All the inner parts of the HOM coupler are separate, and then assembled together by the fixture. Each part may introduces a small error during the installation. When assemble the HOM coupler on the test bench, the angular position of the HOM coupler is defined by labels on the flange and tube. It leads to a few degrees of error. But in general, the broadband results for the measurement and simulated results are agree well.

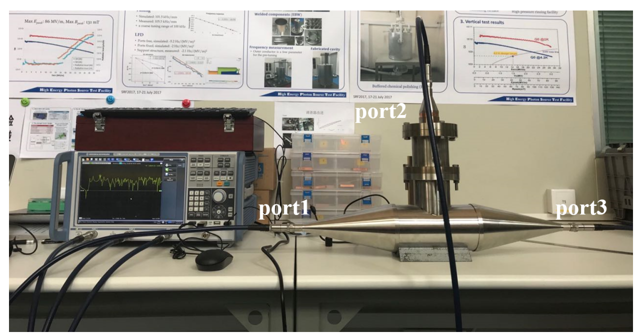

Figure 9: The coaxial transmission line test bench with HOM coupler.

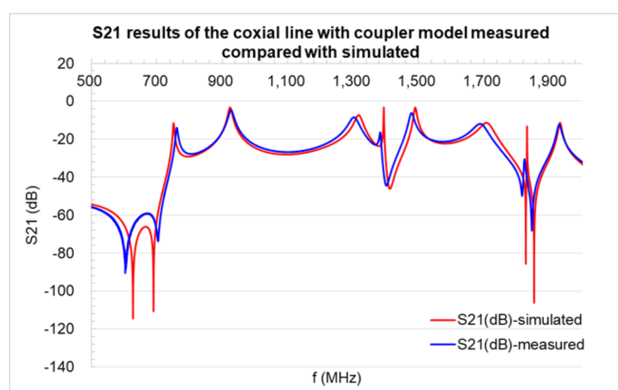

Figure 10: The measured S21 parameters of the HOM coupler compared with simulated.

Different length of different inner parts are changed to see the impact on the transmission properties for the HOM

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coupler. Fig. 11 indicates that the different length of L1 affects a little of the notch frequency and mainly affects the frequencies of the second and third crest which corresponding to the second and fourth higher order modes. Fig. 12 indicates that the longer L2 causes smaller bandwidth for the notch frequency and bring the crests of S21 move to the low frequency side. Fig. 13 indicates that the different length of L3 affects the notch frequency only a little and the longer L3 value brings the crests move to the lower frequency side. The design value for L1, L2 and L3 is kept unchanged, and machining error should be controled.

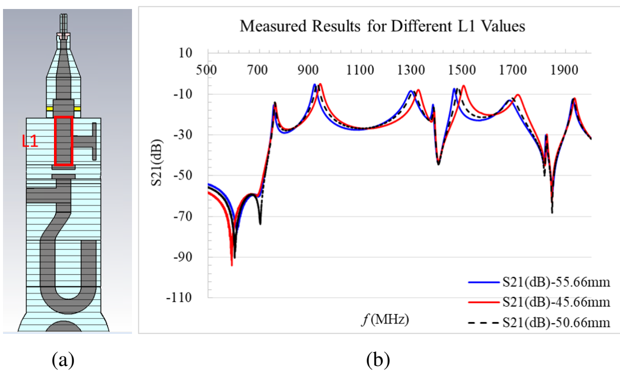

Figure 11: (a) HOM coupler model, (b) measured results for different L1 length.

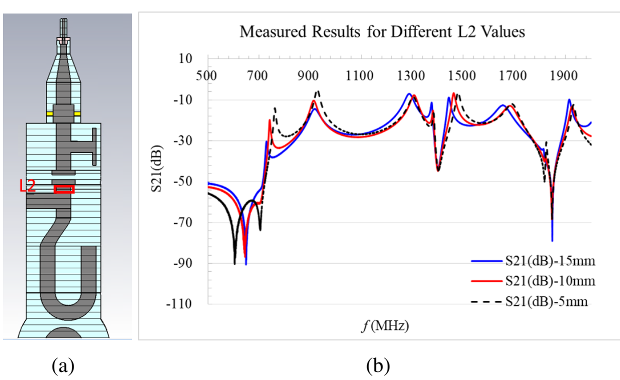

Figure 12: (a) HOM coupler model, (b) measured results for different L2 length.

HOM COUPLER HIGH POWER TEST

100 W Test

The high power test was carried out at room temperature with 1.3 GHz 3 kW solid state power source. Several temperature sensors were put on different location of the test bench as shown in Fig. 14. Finally, the picked up power from HOM coupler port is 104 W, and the input power is 639 W. The temperature near the pickup port is 34.3 °C.

1 kW Test

For CDR design, the upper-limit of the HOM power handing capacity for each HOM coupler is set to 1 kW. In order to

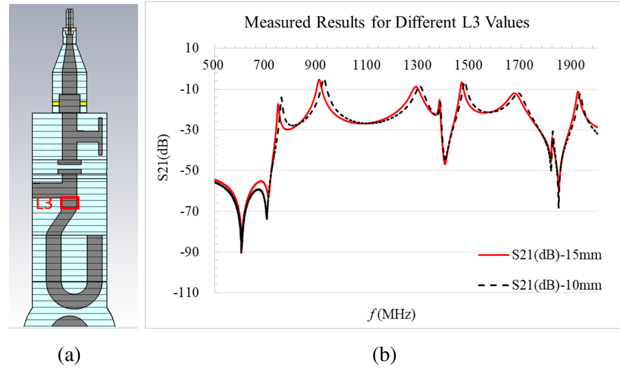

Figure 13: (a) HOM coupler model, (b) measured results for different L3 length.

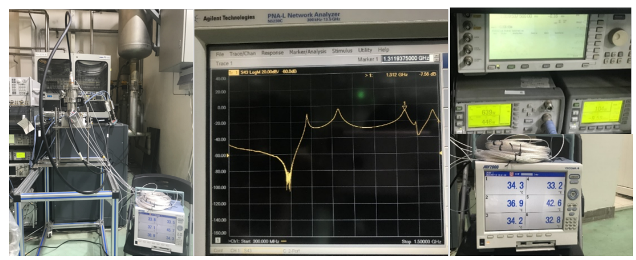

Figure 14: High power test for the HOM coupler at room temperature.

insure the HOM coupler operate without breakdown during the machine running, 1 kW power test under 2 K is planned. A special coaxial line which used to pick up 1 kW power from the HOM coupler and a special test box are currently being explored. Vertical test with cavity and in horizontal test stand are also on our schedule.

CONCLUSION

In this paper, the HOM coupler fabrication status for room temperature test and low temperature test are introduced. Two dismountable stainless steel HOM coupler prototypes and a coaxial line test bench are designed and fabricated for the measurement of the transmission characteristics. The reflection properties of the coaxial line agrees well with the simulated results. The low power test of the HOM coupler shows that the bandwidth of the notch frequency for the notch filter is about 101 MHz, which is wide enough for the fundamental mode damping that need not to be tuned for practical applications. The broadband test results for the HOM coupler agree well with the simulation results. 100 W power test at room temperature are finished and the 1 kW power test at room temperature as well as low temperature are under way. Vertical test and horizontal test of the cavity with HOM coupler are also on our schedule.

ACKNOWLEDGEMENTS

We would like to thank Zhongquan Li, Qiang Ma from IHEP for helping with some simulations, engineering problems and for some useful discussions and suggestions. We

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would also like to thank Jiankui Hao, Fang Wang and Lin Lin from PKU for helping with the the power test. This work was supported by National Key Programme for S&T Research and Development (Grant NO.: 2016YFA0400400) and Xie Jialin Funding.

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