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DESIGN OF THE HIGH POWER INPUT COUPLER FOR CEPC MAIN RING CAVITY

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Abstract

The main ring cavities of CEPC project are two-cell elliptical superconducting cavities operating at 650 MHz in CW mode. Each cavity equips with one high power input coupler and each coupler has to deliver at least 300 kW of CW RF power to the beam. A variable coupling from 1E5 to 2E6 is required to meet different operation modes. Considering the cavities working with high quality factor up to 2E10, the coupler assembled with cavity in class 10 clean room is strongly recommended to protect the cavity from contamination. Also, low cryogenic heat loss is one of the important issues for a large scale CW operation machine. Some of the above requirements should be compromise. Therefore, it's a big challenge to design a high power input coupler fulfilling the above requirements simultaneously. A new coupler that employs 75 Ohm coaxial line sections, a planar ceramic disk window, a coaxial to waveguide transition and a coupling adjusting actuator has been designed. In this paper, the RF design, thermal stress analysis and preliminary mechanical design of the coupler are presented.

INTRODUCTION

CEPC is a 100 km circular electron positron collider operating at 90-240 GeV center-of-mass energy of Z, W and Higgs bosons. The SRF system parameters of the CEPC Main Ring is in reference [1]. Each cavity equips with one power coupler and each coupler has to deliver at least 300 kW of CW RF power to the beam. The different requirements at Z, W and H operation have imposed the use of a variable power coupler with a coupling value varying from 1E5 to 2E6. In the meanwhile, considering the large scale and high performance requirement of CEPC, clean assembly, low cryogenic heat loss, high reliability and low cost are also important issues of the coupler design. The main requirements of power coupler are summarized in Table 1.

The main design challenges are:

- High average RF power: more than 300 kW, CW, TW;
- Wide range of variable coupling: factor of 20;
- Clean assembly: coupler and cavity assembled in class 10 clean room;
- Low cryogenic heat loss: 2 K dynamic heat loss less than 1 W at 300 kW, CW, TW.

Table 1: The Main Requirements of the Power Coupler

Parameters	**Value**
Frequency	650 MHz
Power	300 kW, CW, TW
Q_e	1E5 to 2E6
2 K heat loss	1 W (dynamic, 300 kW, CW, TW)
Assembly	Coupler and cavity assembled in class 10 clean room

RF DESIGN

The power coupler of BEPCII 500MHz SCC has been proved excellent high power handling capability and mechanical reliability [2]. Therefore, we take into account the experience during the CEPC main ring coupler design. The general layout of the coupler assembly is shown in Fig. 1. Like BEPCII coupler, this coupler consists of three sub-assemblies: 1) doorknob to realize the transition from waveguide to coaxial line; 2) RF window to provide RF-transparent vacuum barrier; 3) coaxial line to transfer and feed RF power into the cavity. The outer diameter of the disk ceramic is of the same size as that in the BEPCII coupler; the doorknob dimensions are scaled to adapt 650MHz.

Too meet the special requirements of CEPC main SCC, the structure modifications based on BEPCII coupler are the follow:

- A larger profiled antenna tip is designed to provide a strong coupling;
- Two sections of bellows are adopted on the outer conductor to realize a coupling adjusting;
- The length of the vacuum part reduced greatly to assure the coupler assembled with cavity in class 10 clean room;
- The impedance of the coaxial line changed from 50 Ohms to 75 Ohm to achieve a low dynamic heat loss and increase the multipacting power level above 300 kW.

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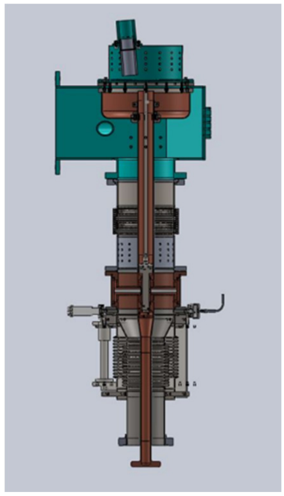


Figure 1: The general layout of the power coupler for CEPC main ring cavity.

Figure 2 shows the simulated S11 curves of the whole coupler assembly. The S11 is better than -45 dB at central frequency. The electric and magnetic field distribution when 400 kW CW RF power passes through in TW mode is shown in Fig. 3. The maximum electric field is 6.15E5 V/m, one fifth of the air breakdown value. Table 2 lists the power dissipation of each component. The total power dissipations is 740 W when 400 kW CW RF power passes through in TW mode, 150 W contributed by the ceramic.

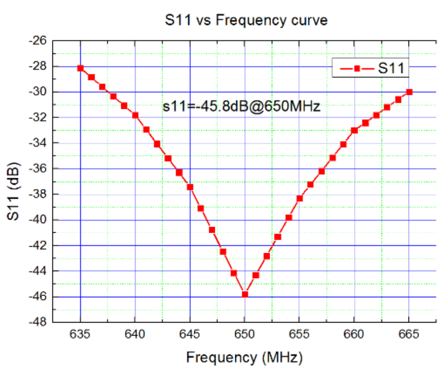
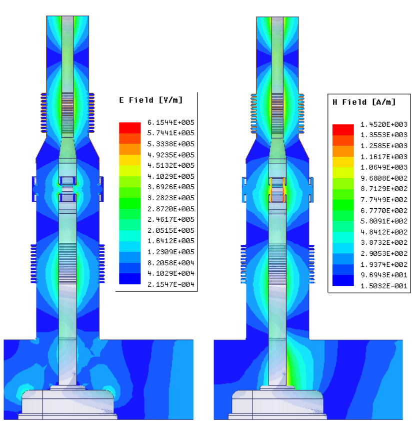


Figure 2: Calculated S parameters of the coupler.



(a) (b)

Figure 3: The electric (a) and magnetic (b) field when 400 kW CW RF power passes through in TW mode.

Table 2: Power dissipation of each component.

Components	Power loss (400 kW, CW, TW)
Ceramic	150 W
Inner window	93 W
Outer window	21 W
Inner coaxial of vacuum part	137 W
Outer coaxial of vacuum part	66 W
Inner coaxial of air part	136 W
Outer coaxial of air part	30 W
Doorknob	102 W
Total	740 W

Both the coupler port (diameter 'Φ' and position 'D' shown in Fig. 4) and the antenna travel range were decided based on the Qe simulation by CST code. It can be seen that the antenna tip penetration depth 'h' should be changed from -9.5 mm to 22.5 mm to meet the coupling adjusting requirement from 2E6 to 1E5. Thus the length of the bellow was chosen as 96 mm, triple of the antenna travel range. Here, a larger profiled antenna tip is designed to provide a strong coupling.

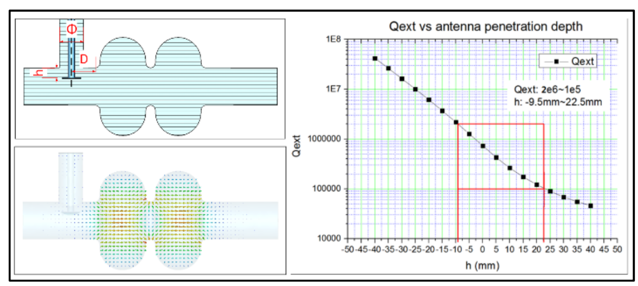


Figure 4: Dependence of Qe on the penetration of the antenna tip into the cavity beam pipe.

THERMAL AND STRESS ANALYSIS

Considering the coupler has to deliver a high CW RF power up to 300kW, dedicated RF-thermal-stress analysis were done by ANSYS; then the cooling scheme was decided based on that. The bellow of the vacuum part would reach more than 600K at the power of 400kW without cooling. So water cooling of the vacuum bellow is necessary. The inner conductor of the window and the coaxial line (vacuum part) was also cooled by water; and the doorknob and the air coaxial line were cooled by air. Figure 5 shows the calculated temperature distribution at the power of CW, 400 kW, TW. As can be seen that the maximum temperature is 345 K, just locating at the ceramic. Figure 6 shows the window thermal stress when 400 kW CW RF power passes through. It can be seen that the maximum thermal stress is 69 MPa, which is far below the ceramic flexural strength (~300 MPa).

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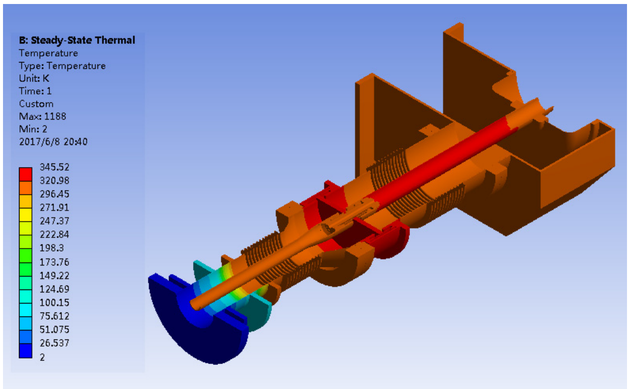

Figure 5: The calculated temperature distribution at the power of CW, 400 kW, TW.

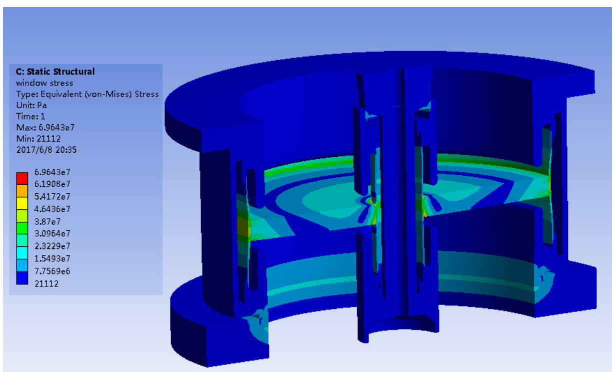

Figure 6: The window thermal stress when 400kW CW RF power passes through.

Since the power coupler also acts as a bridge connecting the room and cryogenic temperatures, it's very important to control the dynamic cryogenic heat loss. Here, the outer conductor was cooled by 80 K and 5 K thermal anchors; and the position of the thermal anchors were optimized to achieve a minimum heat loss. Table 3 shows the calculated static and dynamic (400 kW, CW, TW) cryogenic heat loss.

Table 3: The Calculated Static and Dynamic Cryogenic Heat Loss at 400kW, CW, TW

	Static	Dynamic
2 K heat loss	0.07 W	0.77 W
5 K heat loss	3.60 W	5.46 W
80 K heat loss	22.6 W	26.6 W

PRELIMINARY MECHANICAL DESIGN

A preliminary mechanical design has been completed based on the RF and thermal stress analysis recently.

One big challenge is the design of the coupling adjusting actuator. Figure 7 shows the schematic of the coupling adjusting. Two sections of bellow are arranged on the outer conductor, one on the vacuum part and the other one on the air part. The length of the outer conductor will be changed under the tuning force, thus the antenna tip into the cavity changed accordingly. For the inner conductor, slide scheme was adopted to match the change of the outer conductor, i.e. no inner bellow was used, which avoid the possible overheating and discharging problem. After the adjusting, the inner conductor will be fixed by a clamp ring.

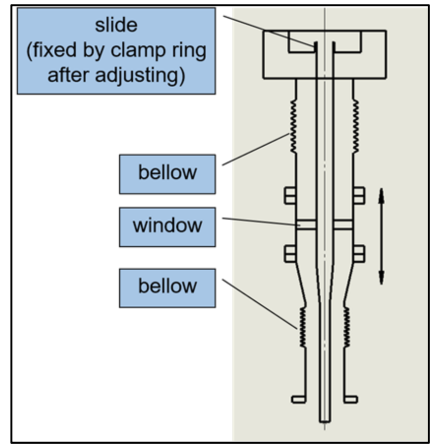

Figure 7: The schematic of the coupling adjusting.

Figure 8 shows the exploded mechanical model of the power coupler.

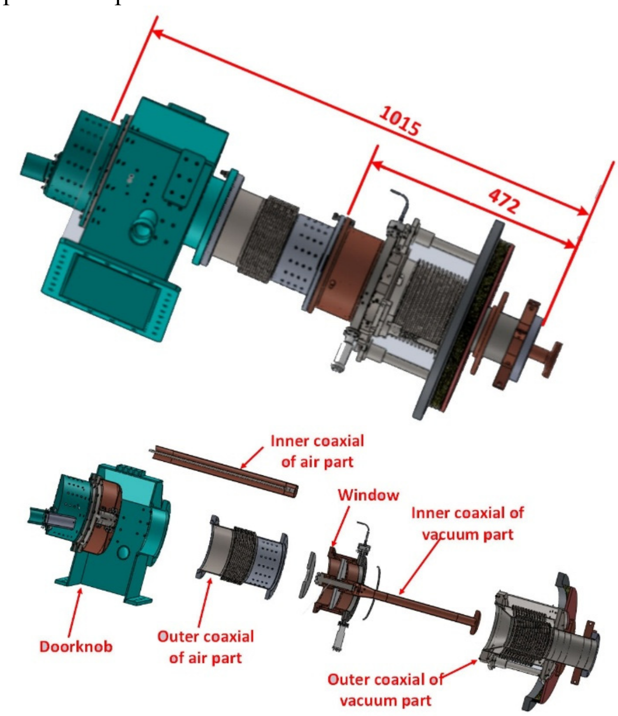

Figure 8: The exploded view of the power coupler.

SUMMARY

A preliminary design of the power coupler for the CEPC main ring cavity has been completed, including the RF design, thermal stress analysis and preliminary mechanical design. More design work will be done, such as the multipacting simulation, DC bias voltage structure design, coupler kick effect estimation and so on. Also more options on the coupling adjusting actuator and low heat loss will be proposed based on further simulation and experiments.

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