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THE DEVELOPMENT OF A PROTOTYPE FUNDAMENTAL POWER COUPLER FOR CiADS AND HIAF HALF WAVE RESONATORS

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Abstract

More than 100 Half-wave resonators (HWR) will be adopted for China Initiative Accelerator Driven System (CiADS) [1] and High Intensity heavy-ion Accelerator Facility (HIAF) [2] at IMP. Each HWR cavity equips with one variable coupling, dual-warm-ceramic fundamental power coupler (FPC). The FPC should be able to transmit up to 30 kW in CW mode. This paper will give an overview of the RF design of the 162.5 MHz CW power coupler. The coupler employs two warm ceramics in a 50 Ohm coaxial line to ensure operation reliability. The results of thermal and thermo-mechanical will also be reported. Two prototype couplers have been fabricated and the RF measurements with low RF power were carried out.

INTRODUCTION

The fundamental power coupler is the critically important component of a superconducting (SC) accelerator. The primary function of the coupler is to delivery RF power from RF source, which located at room temperature and at atmospheric pressure, to a superconducting cavity sat at cryogenic temperature and vacuum. In consequence, the fundamental power couplers for these cavities should be carefully designed.

The superconducting ion Linac accelerator (iLinac) of HIAF is designed to accelerate ions with the charge-mass ratio Z/A=1/7 (e. g. $^{238}U^{34+}$) to the energy of 17 MeV/u. The CiADS makes use of superconducting RF cavities to accelerate H^- ions to over 500 MeV in the first phase.

HIAF and CiADS accelerators desire not only high accelerating gradient, but also high operating efficiency and reliability. Based on the operation experience of China ADS, two-ceramic coupler for SC cavities is the higher safety margin against ceramic failure during operation [3]. Consequently, the dual-warm-ceramic coupler will be adopted for the two SC linear accelerators. The beam current of CiADS will be less than 2.5 mA in the first phase, and it will be upgraded to more than 10 mA in the future. The coupler should be variable to accommodate diverse beam loading at different phase to reduce the cost of power source. The main specifications of power coupler for CiADS and HIAF are listed in the Table 1. It was decided that only one coupler design will be used for all the HWR cavities in face of their diverse power needs. The prototype coupler should be able to test up to 30 kW CW RF power at 162.5 MHz in travelling wave, but it should also be RF conditioned in total reflection mode.

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Table 1: Margin Specifications

	HIAF				CiADS		
	QWR007	HWR015	HWR010	HWR019	DSR042	Ellip062	Ellip082
Frequency (MHz)	81.25	162.5	162.5	162.5	325	650	650
Quality	30+5	66+6	9	24+6	40+4	40+4	24
Qe(10^6)	0.18~0.61	0.36~0.92	0.36~1.02	0.54~1.18	1.08~5.17	2.17~6.64	2.95~5.61
stroke(mm)	-	6	6	6	6	6	10
Operation power (kW)	3	4	7	24	42	88	92
Power at Test Stand (kW)	6	6	10	30	60	100	110

THE PROTOTYPE POWER COUPLER DESIGN

The electromagnetic design and thermal-mechanical simulation of the 162.5MHz prototype coupler will be presented in this section.

EM Design

A general overview of the coupler set is shown in Fig. 1. The coupler has a coaxial geometry, which is connected between the HWR and a "T" transition box. It constituted of a dual-warm-ceramic part, a bellow for adjusting coupling coefficient and an antenna. The RF transmission of the coupler was optimized by CST Studio Suite with its intrinsic optimizer [4].

The coaxial windows are planar annular disk-type made of AL300 alumina ceramic. Bigger out conductor and smaller inner conductor are used to match the two ceramics in the coaxial line.

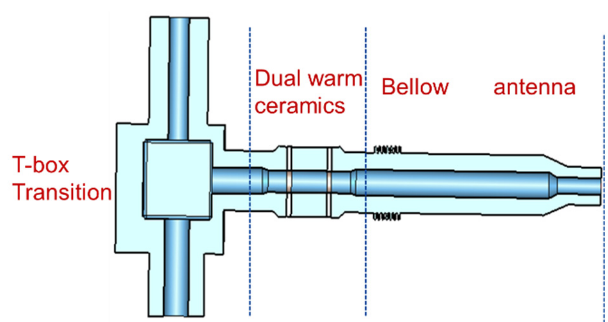

Figure 1: RF model of the coupler.

After a series of optimization, a good S parameter result has been found. As shown in Fig. 2, the coupler presents a minimum of reflexion parameter of -49 dB at a frequency of 162.5 MHz. The simulation results show that the coupler has good transmission properties for broad transition at operation frequency, thereby allowing standard fabrication tolerances.

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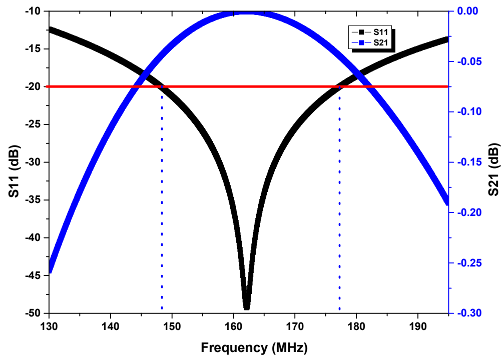

Figure 2: Optimized S-parameter of the coupler.

The change in coupling is made by axial movement of the antenna. The effect on the different bellows extension/compression is simulated. The passband is not sensitive to the inner conductor's displacements, as shown in Fig. 3.

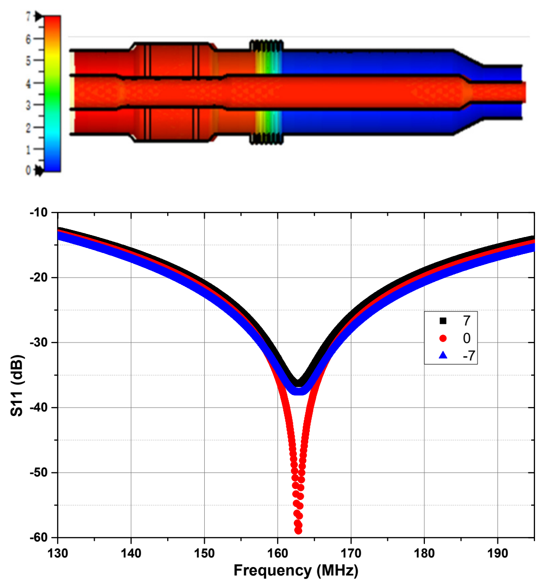

Figure 3: Movement of the inner conductor and the S11 for different bellow position.

The field emission electrons from SC cavity can hit on the ceramic for HWR010 cavity. The design includes the shields in the inner conductor to protect the ceramics from charged particle. The shields also match the tapered coaxial component, as shown in Fig. 4. The electrons from HWR015&019 will not hit the ceramic due to the donut ring shape of the inner conductor.

Thermal-Mechanical Simulation

Thermal stress for different loss tangent of ceramic at 10 kW has been simulated to ensure the safety of dual-warm-ceramic part. The loss tangent is 4E-4 and 3E-4 for Fig. 5 and 6, respectively. The equivalent stress is beyond the weld strength of the two-warm-ceramic joints.

The inner conductor is going to be fabricated of copper (Cu), however the outer conductor will be stainless steel (SS) with the inner coating of copper (20 μm).

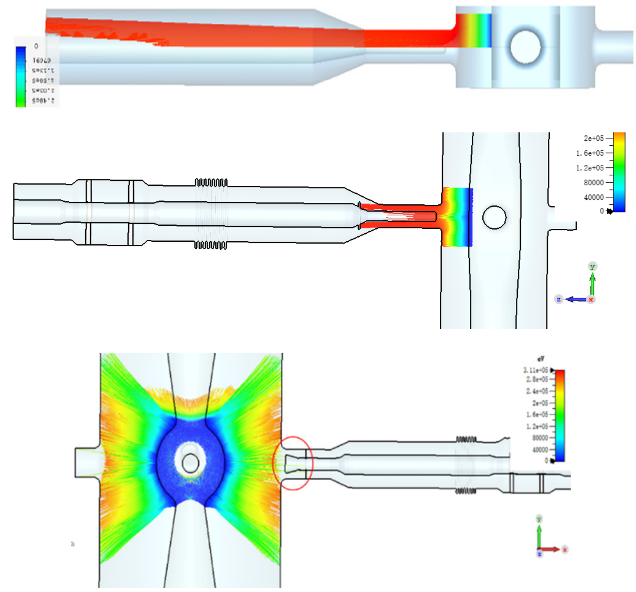

Figure 4: The field emission effect on coupler for HWR010 cavity and HWR015&019 cavity.

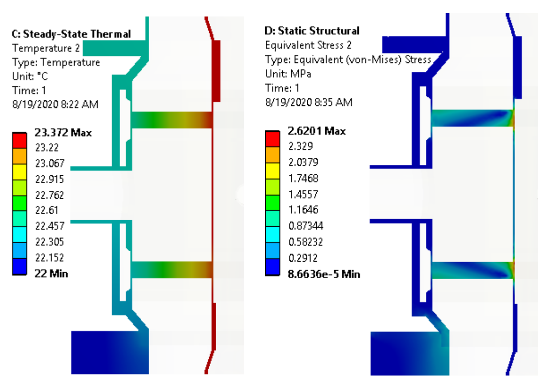

Figure 5: Temperature and equivalent Stress distribution of two-warm-ceramic part for Loss tangent of 4E-4.

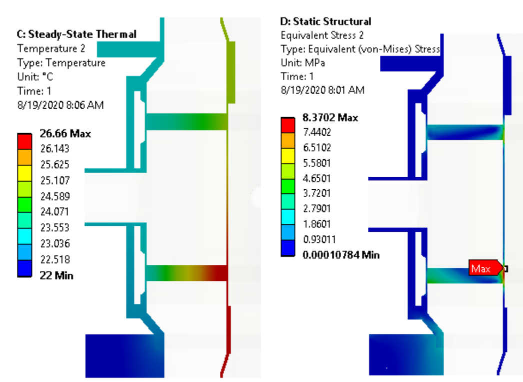

Figure 6: Temperature and equivalent Stress distribution of two-warm-ceramic part for Loss tangent of 4E-3.

The double-wall tube is applied to ensure a thermal gradient between low temperature cavity and the ambient temperature (window level) and to be used as the external conductor for the RF coaxial line. A cooling circuit (helium) at 5 K is used to obtain the required thermal gradient. For re-

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cycling to the refrigerating machine, the output temperature of the helium gas should be less than 75 K. The thermal simulation model is shown in Fig. 7.

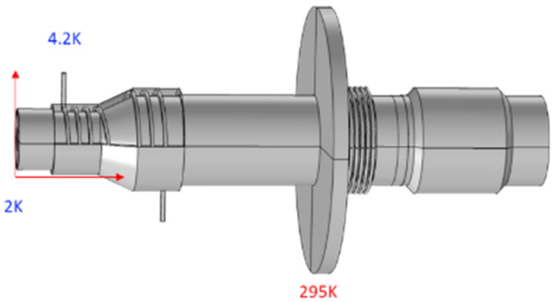

Figure 7: Thermal model.

Table 2 shows the heat load of different gas flux for diverse power. The gas flux is 30 mg/s is appropriate in the situation. The temperature distribution along the outer conductor for various gas flux is shown in Fig. 8.

Table 2: Heat Load of Different Gas Flux

Power(kW)	2K heat load(W)	Gas flux(g/s)	Output temp.(K)
0	3.894	0.01	91.9
10	4.100	0.01	93.6
20	4.314	0.01	95.2
30	4.529	0.01	96.9
0	0.324	0.03	64.9
10	0.382	0.03	66.3
20	0.442	0.03	67.6
30	0.505	0.03	69.0
0	0.070	0.05	46.5
10	0.084	0.05	47.5
20	0.097	0.05	48.4
30	0.113	0.05	49.4

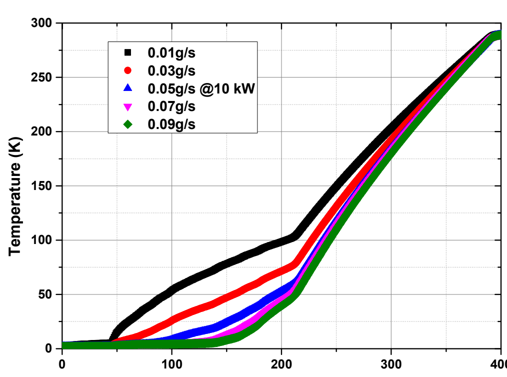

Figure 8: Temperature distribution along the coupler.

The way of connection of inner conductor in air side is shown in Fig. 9. The stress of connecting the inner conductor was simulated, the max. equivalent stress is less than 32 MPa for the torsion of 20 N·m, which is beyond the weld strength of the ceramic joint.

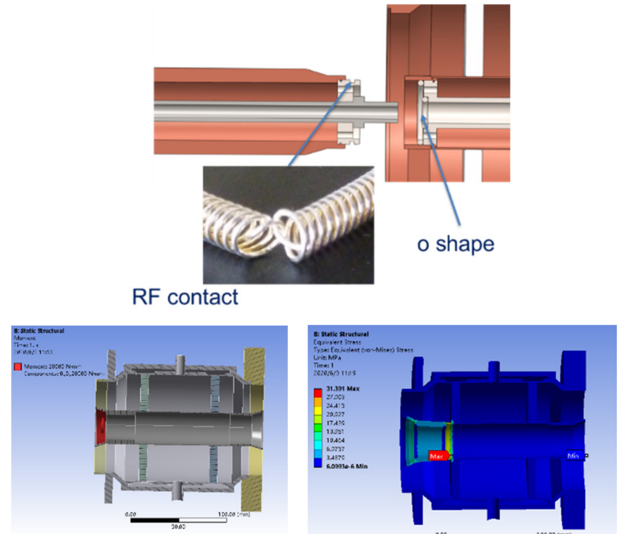

Figure 9: Connection of the inner conductor in air side.

FABRICATION AND LOW POWER MEASUREMENTS

A prototype has been fabricated and low power measurement was carried out. The measurements fulfil the acceptance condition and demonstrate a low return loss values less than -30 dB for all frequencies between 158 MHz and 166 MHz, as shown in Fig. 10.

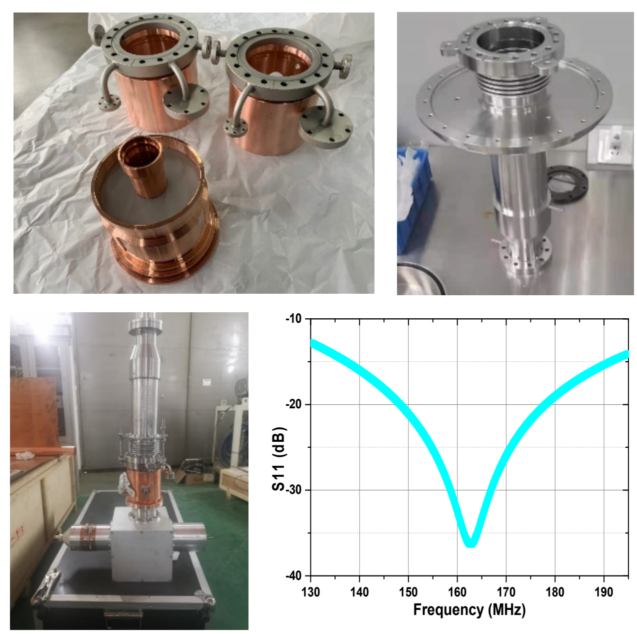

Figure 10: Manufacture and low power measurement.

CONCLUSION

A two-warm-ceramic coupler has been designed for HWR cavities of CiADS and HIAF. Two coupler prototype sets were manufactured. Acceptance tests are on-going. The reception of couplers is planned for autumn 2021. The high-power processing will be the next major validation stage.

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