HIGH POWER INPUT COUPLERS FOR C-ADS

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Abstract

High power input couplers are key components of the of the high power input couplers for C-ADS.

INTRODUCTION

Accelerator Driven sub-critical System (ADS) is a proton accelerator-based facility to produce energy and to destroy nuclear waste efficiently. China ADS (C-ADS) project is aiming at constructing a 15 MW continuous wave (CW) proton linac of 1.5 GeV and 10 mA from 2011 to 2030s. For Phase-I, the goal is to build a CW proton linac of 25 MeV and 10 mA by around 2016 [1]. The phase-I linac consists of two injectors and one main linac section, as shown in Fig. 1. Four types of superconducting cavities (SCCs) of two frequencies are adopted.

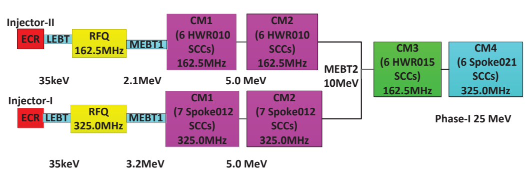

Figure 1: The schematic of C-ADS (Phase-I).

All input couplers for the SCCs are developed in IHEP. Up to now, all injector couplers have been assembled with both the Test Cryomodules (TCM) and the first formal cryomodules (CM1); joined the cavity RF processing and beam commissioning. In the meanwhile, the design of the input couplers for the main linac has been completed and to be fabricated soon.

In this paper, we will describe the design, manufacture, high power test on the test stand and the RF processing in the cryomodule of the couplers.

DESIGN OF THE COUPLERS

Both injectors and the main linac consist of two cryomodules; each cryomodule houses six or seven cavities; and each cavity is equipped with one input coupler. The main parameters of each coupler are listed in Table 1. Since the requirements of the input couplers for the same type of cavities for injectors and main linac are similar, only the design of the injector couplers will be illustrated here. Thoroughly and carefully simulations were done to determine the RF dimensions, mechanical structures, cooling methods and so on, which have been described in detail [2], [3].

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Table 1: Main Parameters of the High Power Input Couplers for C-ADS SCC (Phase-I)

Parameters	Spoke -012	HWR -010	Spoke -021	HWR -015
Frequency (MHz)	325	162.5	325	162.5
RF power (kW)	10	20	25	25
Qext	7.0E5	7.0E5	8.0E5	6.7E5
Dynamic losses to 2K (W)	0.24	/	/	/
Dynamic losses to 4K (W)	2.20	0.18	3.10	1.85

The general layouts of couplers for two injectors are shown in Fig. 2. As can be seen, both couplers can be divided into three main parts.

An open-ended 50 Ω coaxial line provides coupling to the cavity. The inner conductor is made of OFHC and cooled by water. The outer conductor is a stainless steel tube, with the inner surface copper-plated with 3 times of skin-depths of copper to reduce RF losses. The cooling of the outer conductor decides by the cavity operation temperature and the heat losses. The outer conductor of the coupler for Spoke-012 cavity is cooled by a thermal anchor at 4 K by helium and at 80 K by nitrogen; and the outer conductor of the coupler for HWR-010 cavity is cooled with 4 K helium gas through a double-wall tube.

A RF window affords RF-transparent vacuum barrier. The window is similar to that of the coupler for BEPCII SCC which proved excellent performance [4]. A coaxial planar ceramic made of 97.6% alumina is applied. The RF design of the window focuses on impedance matching, the resonant mods far from working frequency and no multipacting on the operation power level; the mechanical design of the window biased towards on a safe thermal stress, the easier ceramic-copper brazing and fully protection of the window. The window is equipped with three monitor ports to detect electron current, vacuum pressure and discharging light. The inner conductor of the window is also cooled by water.

A T-box provides the matching to the coaxial line. Due to the very low working frequency, the traditional transition structures of "doorknob" [4] and coaxial line with quarter wave short-circuit are too large. The T-box, which consists of one outer box, one inner box and one moveable short-circuit plate, is an ingenious design to solve the problem. The size of outer and inner boxes, the radius of chamfers, and the position of the short-circuit plate were carefully optimized aiming at good impedance matching and low peak electric field. The T-box is made of aluminum for weight reduction. Based on the RF-thermal analysis using ANSYS, no cooling of the

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T-box is acceptable as the passed RF power less than 15 kW.

MANUFACTURE OF THE COUPLERS

Eleven Spoke-012 couplers (two prototypes and nine formals) and ten HWR-010 couplers (two prototypes and eight formals) have been fabricated since 2012. Fig. 3 shows some fabricated components. During the prototypes fabrication, some difficulties were initially encountered.

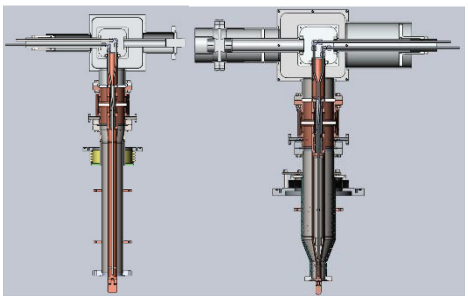

Figure 2: The general layout of high power input couplers for C-ADS: (a) Spoke-012 SCC input coupler; (b) HWR-010 SCC input coupler

One challenge is the copper plating. Sometimes, defects appeared on the welded seams; sometimes the plated copper around the taper disappeared after baking. After fine adjustment of the plating process and the mechanical design, durably plated tubes were finally achieved.

RF window is the most critical component. The window brazing is difficult due to its complex structure. Through exploration, the window brazing procedure was optimized to reduce the number of the ceramic thermal cycling. 10 nm TiN coating was processed after the window brazing.

Now seven more Spoke-012 couplers and twelve more HWR-010 couplers are under fabrication; and to be tested and assembled with cryomodules by the end of 2015.

Figure 3: The fabricated coupler components.

HIGH POWER CONDITIONING ON THE TEST STAND

High Power Test Bench

Due to low working frequency, the traditional test benches such as coupling waveguide [5] and resonant cavity [6] are too big. So special test benches were desired to meet the requirements of low working frequencies (162.5 MHz or 325 MHz), broad bandwidths and high power capabilities. The conceptual design of the test bench is shown in Fig. 4, as can be seen it's an approximate capacitor-loaded coaxial cavity. The size of the test bench is greatly reduced by the loaded capacitor. Especially, the different working frequencies of such kind of test benches were easily obtained by only changing the dimension of "d", i.e. the distance between the capacitor plate and the top plate. The high power systems of 162.5 MHz and 325 MHz are show in Fig 5 and Fig. 6 respectively. Further details about the high power test systems can be found in [7] [8].

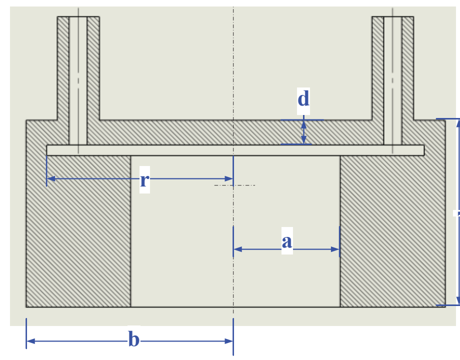

Figure 4: The conceptual design of the test benches.

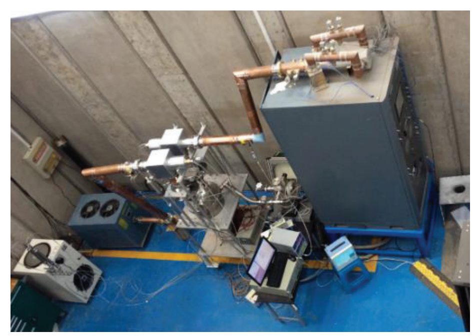

Figure 5: The high power test system for couplers of 162.5MHz HWR SCC.

Figure 6: The high power test system for couplers of 325 MHz Spoke SCC.

High Power Test Results

Both traveling wave (TW) and standing wave (SW) modes conditioning are processed for each coupler, initially with pulsed, TW mode. For SW mode conditioning, a short circuit connected with the downstream coupler is moved, with step of λ/8 over a whole λ/2 length, to assure that all phases seen by the couplers.

The first two prototypes for HWR-010 cavity were tested up to 20 kW CW with TW mode in July, 2012. However, the outer conductor of the narrow coaxial was found overheating. Then improvement was done by reducing the length of the narrow coaxial [7].

The first two prototypes for Spoke-012 cavity were tested in January, 2013. It took about 8 hours to reach 10 kW with CW in TW mode. The maximum temperature around the window is 31.9 ℃ [8].

Seven formals for 325 MHz Spoke-012 SCC for Injector-I and six formals for 162.5 MHz HWR-010 SCC for Injector-II have been high power tested up to the nominal power levels in both TW (Spke-012: 10 kW; HWR-010: 20 kW) and SW modes (Spke-012: 5 kW; HWR-010: 8 kW). Generally it took 10 to 15 hours for TW conditioning. For SW mode, the conditioning of the first position took 2 to 5 hours; and less than 1 hour for the rest of positions.

RF PROCESSINGS IN THE CRYOMODULE

Couplers of 325 MHz Spoke-012 SCC for Injector-I

Two prototype couplers of 325 MHz Spoke-012 SCC were assembled in the test cryomodule (TCM) in the end of 2014. Then the RF processing started in January, 2015. While unexpected fatal window crack were encountered after two weeks of RF processing without beam. The cracked window was unassembled and inspected. Fig. 7 shows the vacuum side of the window before assembled and after disassembled from the cavity. It can be seen that the color of the vacuum side of the ceramic surface changed from white to yellow.

(a) (b)

Figure 7: The vacuum side of the window: (a) before assembled in the cavity; (b) after disassembled from the cavity.

Further inspection and experiments were done; and the following characteristics were found: 1) Power can easily reach to 3 kW when the cavity detuned; however, once cavity tuned, crack happened after several times of periodically triggered arc events; 2) Large X-ray dose was measured near the window when cavity gradient above 3 MV/m; 3) The vacuum side of the cracked ceramic turns on a uniform yellow color, while the air side is still white; 4) There is no electron or iron bombarding trace on the RF surface of the cracked coupler.

Based on above characteristics, we speculate the reason of the ceramic crack is as follows: First, serious FE happened in the cavity, then electrons flied out from the coupling port and impacted directly on the vacuum side of the ceramic, which made the ceramic charged; and then electrostatic discharging happened once exceeding the ceramic breakdown voltage; Finally, the strong energy released from the discharging made the ceramic punctured along the thickness direction and resulted in fatal vacuum leak.

Further experiments were carried out to verify the above speculation. First, a piece of Teflon plate were put into the space between the ceramic and the cavity coupling port to barrier the FE electrons; then the cavity gradient were increased to the level of ceramic crack happened before (>3.5 MV/m). We found that the ceramic never cracked after Teflon plate shielding. Second, considering the pickup port is geometric symmetry with the power coupler port, a "bias network" was connected with the pickup signal to capture the voltage produced by FE electrons. Fig. 8 gives the DC voltage and X-ray dose at different cavity gradients, as can be seen the expected DC voltage was detected once the X-ray dose arising. The experiments well proved the above speculation.

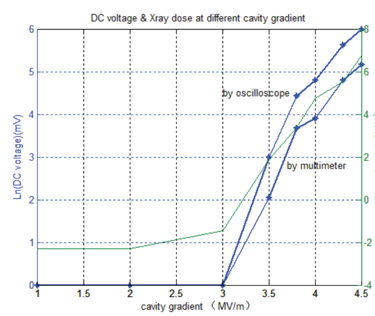

Figure 8: The DC voltage and X-ray dose at different cavity gradients.

A lesson learned from the in-cryomodule RF processing is that cavity FE may resulted in fatal ceramic crack, especially for the low beta SCC with coupler located in the cavity wall instead of beam pipe. Improvements have been done, focusing on avoiding cavity FE, such as improving the coupler assembly and conditioning procedure. Now, seven formals have been assembled in the cryomodule (CM1 for Injector-I), as shown in Fig. 9. The room temperature RF processing of the couplers up to CW 5 kW have been completed in 2 days. And the cryogenic temperature RF processing and beam commissioning are undergoing now. No ceramic cracked after improvement.

Figure 9: The in-situ input couplers of 325 MHz Spoke-012 SCC for Injector-I.

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Couplers of 162.5 MHz HWR-010 SCC for Injector-II

One prototype coupler of 162.5 MHz HWR-010 SCC for Injector-II were put into beam operation successfully with the TCM in 2014. Then six formals were installed in the cryomodule (CM1 for Injector-II) and processed without and with beam successively in the middle of 2015. 10 mA proton has been accelerated from 2.1 MeV to 5 MeV now. RF power up to 4 kW CW per coupler was applied during beam operation. The in-situ input couplers of 162.5 MHz HWR-010 SCC for Injector-II is shown in Fig. 10.

Figure 10: The in-situ input couplers of 162.5 MHz HWR-010 SCC for Injector-II.

SUMMARY

Four prototype couplers for Injector-I and Injector-II have been designed, fabricated, tested and joined the beam commissioning with the Test Cryomodule (TCM). A lesson learned from the in-cryomodule RF processing is that the cavity FE may resulted in coupler ceramic crack. Seven formals for 325 MHz Spoke-012 SCCs are under the cavity RF processing and beam commissioning now; and no ceramic cracked after improvement. Six formals for 162.5 MHz HWR-010 SCCs for Injector-II have joined the beam commissioning, which accelerated 10 mA proton from 2.1 MeV to 5 MeV. Nineteen more formals for CM2 (seven for Injector-I; twelve for Injector-II) are under fabrication and to be high power tested in the end of 2015. In addition, the design of the input couplers for the main linac has been completed and to be fabricated soon.

REFERENCES

[1] Edited by Jingyu Tang, Zhihui Li, “Conceptual Physics Design on the C-ADS Accelerators”, (2012).
[2] X. Chen et al. “Development of Power Coupler for Superconducting Spoke Cavities for China ADS Proton Linac”, Proceeding of SRF 2013.
[3] F.B. Meng et al. “Study and design of RF coupler for Chinese ADS HWR superconducting cavity”, Chinese Physics C Vol. 38, No. 11 (2014) 117002.
[4] T. M Huang, W. M. Pan et al. “High power input coupler development for BEPCII 500MHz superconducting cavity”. NIM in Physics Research A 623 (2010): 895-902.
[5] E. Kako, H. Hayano et al. “High Power Input Couplers for the STF Baseline Cavity System at KEK”. Proceeding of SRF 2007.
[6] V. Veshcherevich, “High Power Tests of Input Couplers for Cornell ERL Injector”, Cornell University, Ithaca, NY, USA.
[7] F.B. Meng. Study of High Power Input Coupler for HWR Superconducting Cavity (Ph.D. Thesis). Beijing: Institute of High Energy Physics, CAS, 2014 (in Chinese).
[8] X. Chen et al. “Coupler conditioning and high power testing of ADS Spoke cavity”, Chinese Physics C Vol. 38, No. 2 (2014) 027001.