DEVELOPMENT OF POWER COUPLER FOR SUPERCONDUCTING SPOKE CAVITIES FOR CHINA ADS PROTON LINAC

X.Chen#, W.M.Pan, T.M.Huang, Q.Ma, F.B.Meng, H.Y.Lin, Y.H.Peng

IHEP, Beijing, China

Abstract

The ADS proton linac adopts β =0.12 superconducting Spoke cavities. Each cavity is powered via a 325 MHz coaxial power coupler. The coupler is to feed 6 kW maximum power though it is designed to handle at 15 kW .Two coupler sets have been made by IHEP so far, and a 10 kW RF power in continuous travelling wave mode has passed through the coupler during high power test in late January 2013. An introduction of this coupler design and the room temperature test results are presented in this paper.

INTRODUCTION

Construction of China Accelerator Driven Sub-critical System (ADS) Injector-I is being carried out at Institute of High Energy Physics (IHEP). One of the important tasks is to fabricate 58 power input couplers for diverse Beta superconducting (SC) Spoke cavities. Each cryomodule contains 6 cavities while each cavity has a single coaxial type input coupler with fixed coupling .The input coupler has to deliver a radio frequency (RF) power in continuous wave (CW) mode up to 6 kW to the cavity and beam load. Since January 2013, we have been testing couplers of this type at room temperature test stand [1]. The results of the test show that coupler of this design is capable of transfer 10 kW CW power stably. Now this coupler is receiving horizontal test with the Spoke cavity attached to cryostat. Main parameters of this coupler are summarized in table 1.

Table1: Main Parameters of Spoke Cavity Coupler

frequency	325MHz
type	Coaxial, antenna E-coupling
window	Single, warm , coaxial disk
Coupling	fixed
Q_{ext}	7.1E5
Input power	Max. 6kW
impedance	50Ω

GENERAL DESCRIPTION

The coupler is of coaxial type of 50 Ω with antenna E-coupling design. A single coaxial planar disk window is set on the warm part at 300 K to form a vacuum barrier. Purity of the alumina ceramic is 97.6%. The cooling system consists of a two-way water channel and the inner conductor, inner ceramic and inner conductor of air side are cooled in that order. The antenna tip is cooled by conduction. Two thermal anchors of 5 K by helium and 80K by liquid nitrogen are attached to the outer conductor to ensure the temperature transition from 300 K to 2 K.Outer conductor is stainless steel with a thin copper layer while inner conductor is OFHC copper. The other parts in the air side are made of aluminum, for the sake of less mechanical stress. The cross sectional view of the coupler is shown in fig.1.

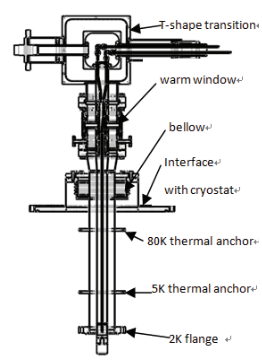

Figure 1: Cross section of the input coupler

CALCULATIONS

S11 and S21 parameters were calculated between the coaxial input line $3\frac{1}{8}''$ inch and the outlet of φ80mm without the antenna extremity using HFSS code. Calculation results are listed in Table 2. The geometry of T-shape transition is a crucial part to satisfy with the matching condition as it is very sensitive to S parameters and nominal frequency. The T-box shape size, the distance between the inside and outside of T-box, and the length of the short circuit, were rather sensitive to the RF performance. Therefore, the above dimensions were varied to find the optimum return loss and insertion loss. Furthermore, the T-shape transition contributes to the on-line adjusting of VSWR in RF conditioning. The proper insertion of ceramic and teflon also affects the transmission performance.

#chenx@ihep.ac.cn

Table 2: Calculation Results (@325MHz)

	S11	S21 (MAG)	Bandwidth (at -20dB)
Results	-49dB	0.9999	±15MHz
Goals	<-25dB	-	±5MHz

Heat loads of the coupler on the cryogenic environment calculated by ANSYS [2] are summarized in Table 3. The outer conductor is made of stainless steel with a 10 um thick copper electro-plated in the surface carrying RF currents, so as to reduce the RF loss and improve RF performance. The location of the two copper thermal anchors and the total length of the coaxial line are carefully optimized for the reduction of the static loss to 2 K and 5 K.

Table 3: Coupler Heat Load per Cavity

	2K(W)	5K(W)	80K(W)
Static	0.005	1.10	11.82
At 15kW(CW, TW)	0.31	3.11	12.46

The inner conductor shows an excessive heating at 15 kW RF power. The 25 °C water cooling is efficient and the temperature of inner conductor decreased dramatically. Thermal simulation show that the temperature of the inner conductor is then kept at 298 K±1 K for 15 kW input power. A comparison of temperature distributions with and without water cooling is carried out. The temperature of inner conductor in different positions is showed in fig. 2.

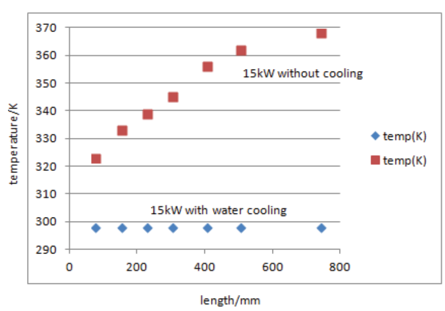

Figure 2: Temperature distributions along inner conductor

The coupler adopted traditional choke structure window. RF design of the window was simulated using HFSS. As shown in fig. 3, the highest filed was occurred at the inner choke tip with the electric field strength of 1.5E5 V/m which was far less than the breakdown electric field in air of Ebra=3E6 V/m[3].

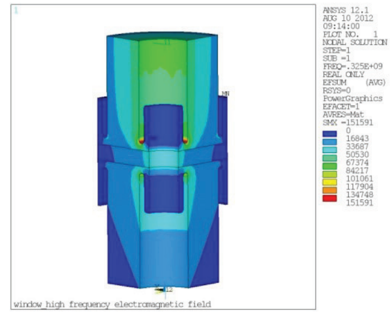

Figure 3: Distribution of electric field at 15kW, TW

Thermal stress has been evaluated due to the delicate ceramic–to-metal brazing [4]. The inner window frame shares water cooling with inner conductor, and water cooling effectively reduces thermal stress by one order of magnitude. The results of thermal stress are showed in fig. 4. The maximum stress value with water cooling laid the outside weld and the value was 4.17 MPa which was only a fraction of the ultimate flexural strength of 296 MPa of the material. The simulation results indicated that the properties of the AL 300 ceramic are satisfactory.

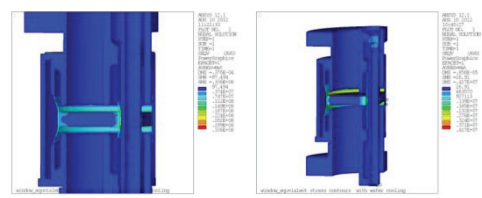

Figure 4: Thermal stress on the ceramic window (left: without cooling; right: with water cooling)

TEST STAND

Two opposing couplers were attached to a test stand that allowed baking and following conditioning of both couplers simultaneously. The test stand was custom-designed, aimed to test the power transferring capability of the coupler [5]. Vacuum was formed between the two warm windows and pumped by an ion pump of 200L/s, in addition an aspirator pump of 400L/s. The test stand was supplied with up to 10kW RF power from a solid-state amplifier. The two couplers and the connecting test stand were matched to maximize the transmission RF power. The power was transferred from upstream coupler (1#) to the downstream coupler (2#) via the test stand and terminated with a matched water load at the end. A picture of block diagram for coupler test was shown in fig.5. The inner conductor and inner window frame shared common water cooling while the outer conductor was cooled by static air. Three monitoring ports were set close to the window including vacuum gauge, arc discharge and electron current monitor. These monitoring instruments are very important to prevent a fatal discharge breakdown of the ceramic windows[6]. One of the above signals exceeding the preset threshold will cause a fast cut off of power. Another vacuum gauge was placed at the side-wall of the test stand.

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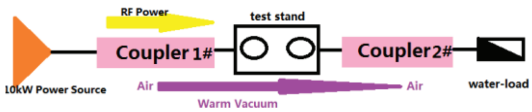

Figure 5: Block diagram for coupler test

CONDITIONING AND HIGH POWER TEST

In advance of assembling, all coupler components and other associated parts were cleaned following our procedure to assure ultra cleanness. Couplers were stored in special container for protection of oxidizing and transferred to the test stand. We baked the system under vacuum for about 3 days below 115 °C in concern of the melting point of indium wire. Conditioning with high RF power before attaching the assembly to the clean cavity is important [7]. A photo of the power test site was shown in fig. 6. At low RF power, we adjusted the two short circuits of our couplers to minimize reflected power in the transmission line. The voltage standing wave ratio (VSWR) value was adjusted to 1.15 at 325 MHz that indicated less than 0.5% input power was reflected. This showed a good agreement with the previous simulation of S11 = -49 dB.

Figure 6: Photo of the test site

While increasing the RF power in short steps, a fast interlock system run which will immediately cut off the RF power if vacuum bursts or arc events occurred. Only conditioning with continuous wave method was adopted. It took about 8 hrs of RF conditioning without major arc actions in the coupler to reach 10 kW. History of high power test is shown in fig. 7. No seriously vacuum bursts or discharging encountered. However, most of the interlock events occurred below 2.5 kw and above 8.2 kW. Between 2.5 and 8.2 kW there were very few events and the conditioning time was less than three hours (see fig.8). Temperature around ceramic windows ranged from 31.1 to 31.9 °C at the power of 10 kW. Fig. 9 presented plot of RF power and temperature during the test.

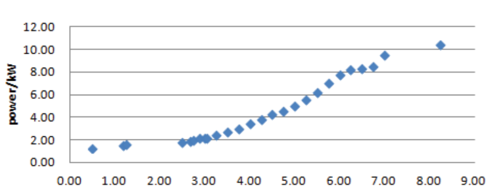

Figure 7: History of high power test

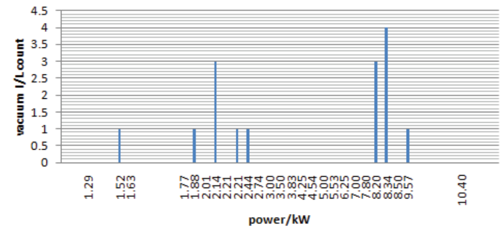

Figure 8: Number of vacuum interlocks

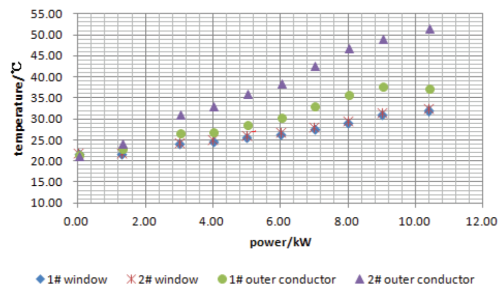

Figure 9: Temperature as a function of RF heating

In the process of testing, we observed unexpected temperature difference between the two outer conductors, one had a temperature of 6-10 °C higher than the other. (see fig.9). After exchanging one with the other, the same result as before. We supposed it was the inner coating surface that may lead to this phenomenon.

SUMMARY

The simulation is helpful in reducing the potential possibility of coupler failure. In the high power test, a RF power of 10.4 kW was reached smoothly which was limited by the klystron available. Temperature differences between the two outer conductors need to be well understood. Furthermore more, in future test of other couplers, we hope to gain a better understanding of the processing limitations.

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