THE DEVELOPMENT OF A HIGH POWER INPUT COUPLER FOR CHINA ADS INJECTOR I RFQ

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Abstract

A 325 MHz RFQ is designed to accelerate a beam current of 15 mA in CW mode with injection energy of 35 keV and output energy of 3.2 MeV for China Accelerator Driven sub-critical System (ADS) injector I. Total RF power of 320 kW has to be delivered into the RFQ cavity. For reliable operation, four input couplers are adopted to share the driven power. A coaxial loop type input coupler is developed. The coupler features a Tristan type RF window, a doorknob to realize the transition from a half-height WR2300 waveguide to a coaxial line and a coaxial line with a coupling antenna loop. Two prototypes of the window and inner conductor assemblies have been fabricated and received high power test. The prototypes were tested up to 100 kW CW RF power in traveling wave mode. This paper will describe the design, fabrication and high power test of the coupler in details.

INTRODUCTION

The injector-I for China ADS consists of an ECR ion source, a Low Energy Beam Transport (LEBT), a 325 MHz RFQ, a Medium Energy Beam Transport (MEBT) and a 325 MHz superconducting RF linac with several Beta 0.12 spoke cavities. The RFQ is used to accelerate a design beam current of 15 mA in CW mode with injection energy of 35 keV and output energy of 3.2 MeV [1]. A driven RF power of 320 kW has to be feed into the RFQ cavity. For reliable operation, four input couplers are adopted to share the driven power. Each coupler needs to handle about 80 kW RF power. The total length of the RFQ is limited within 4.8 m, which consists of two physical resonantly coupled segments (See Fig.1). Two of the couplers are located at the vane-I and vane-III of the first segment. The other two are arranged at the vane-II and vane-IV of the second segment.

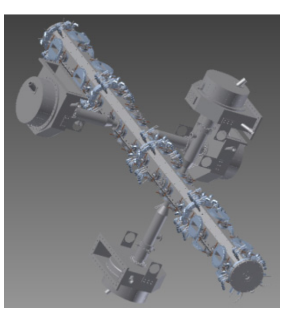

Figure 1: The structure of China ADS injector-I RFQ.

RFQ employs either iris or loop for RF power coupling. Accordingly two types of input couplers are adopted, ridge-loaded waveguide type and coaxial loop type. Though ridge-loaded waveguide couplers have simple structure and easy to cool, a multipacting may occur in the vacuum waveguides near the iris, which has been demonstrated in the LEDA RFQ high power conditioning [2]. On the other hand, coaxial loop couplers are relatively easy to adjust coupling factor and modify multipacting power levels. Many RFQs tend to select coaxial loop type couplers, such as IFMIF/EVEDA RFQ [3], TRASCO RFQ [4], SNS RFQ [5], KTF RFQ [6] and so on. Also, a coaxial antenna type input coupler used in the BEPCII 500MHz superconducting cavities has been proved excellent high power handling capability and mechanical reliability [7]. To take use of the successful experiences, a coaxial loop type input coupler is adopted in China ADS inject-I RFQ. This paper will give a detailed description of the coupler development.

RF STRUCTURE DESIGN

The main requirements of China ADS inject-I RFQ and its main input coupler are summarized in Table 1.

Table 1: Main requirements of China ADS inject-I RFQ and its main input coupler

Parameters	Value
Frequency (MHz)	325
Injection energy (keV)	35
Output energy (MeV)	3.2128
Pulsed beam current (mA)	15
Beam duty factor	100%
Total power (kW)	320.94
Number of input couplers per cavity	4
Maximum RF power per input coupler (kW)	CW, 80
Input coupler coupling factor	1.18

The coupler is of coaxial loop type, which consists of three parts: a doorknob, a RF window and a coaxial line with a coupling loop. The general layout of the coupler assembly is shown in Fig.2.

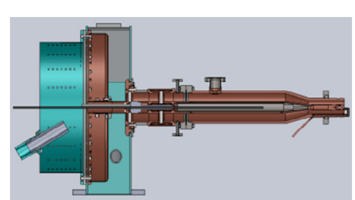

Figure 2: The general layout of the coupler assembly.

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The doorknob is adopted to realize the matching transition from a half-height WR2300 waveguide to a 50 Ohms coaxial line. It is composed of a half-height WR2300 waveguide, a doorknob- shape inner component with a large diameter of 510 mm and a RF shielding cover.

The RF window is similar to the windows used in BEPCII SCCs input couplers that proved excellent performance. A coaxial planar ceramic made of 97.6% alumina instead of 99.5% alumina is applied as vacuum barrier for easier brazing. The window is equipped with three monitor ports to detect electron current, vacuum and discharge light.

Due to space limit, the diameter of the coupling port on the RFQ cavity is only 48 mm. A tapered coaxial transmission line section is used to connect the coupling port and the 95.3 mm 50 Ohms coaxial line. A vacuum pump port with RF shielding slots is arranged near the RF window to reduce the gas condensation. An antenna loop is used for power coupling.

The optimum RF structures of doorknob, RF window and coaxial line are determined by simulation with respect to impedance matching, peak electric field and some manufacturing issues. Figure 3 gives the RF power transmission performance of the whole coupler. We can see that the reference coefficient of S11 is -37 dB at 325 MHz and the bandwidth is about 25 MHz. Here the bandwidth is defined as the frequency bandwidth when S11 less than -20 dB.

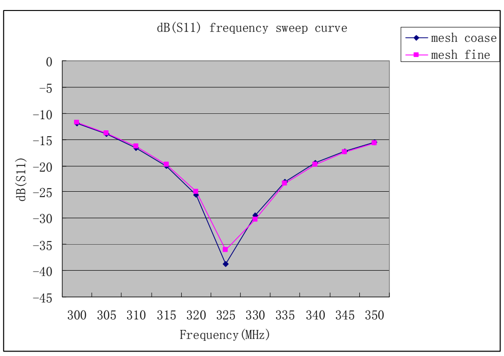

Figure 3: The reference coefficient of S11 is -37 dB at 325 MHz and the bandwidth is about 25 MHz.

COOLING DESIGN

As the coupler operates at CW mode and needs to transfer RF power up to 80 kW. One of the main challenges is the cooling design, especially the cooling of the antenna loop.

Cooling design has been done carefully base on the multi-physics analysis of RF-thermal-structure. Table 2 shows the calculated RF heat of each part when 50 kW and 100 kW RF power passed though. Since the RF window is one of the most critical parts needs to be cooled specially, the temperature and thermal stress of RF window are analyzed further. Figure 4 shows the thermal stress distribution when 100 kW RF power passes though in TW mode. It can be seen that with 25 ℃ cooling water on the inner conductor of the window, the maximum thermal stress reduced to 45 MPa, which is far below the ceramic flexural strength of 330 MPa. The outer conductor of the coaxial line is also cooled by 25 ℃ cooling water with a 6 mm copper tube winded around it.

Table 2: The estimated RF heat of each part of the input coupler for China ADS inject-I RFQ

Pin(kW) / Heat load(W)	50	100
Ceramic	18.7	37.4
Inner conductor	27.3	55.6
Outer conductor	11.4	22.8

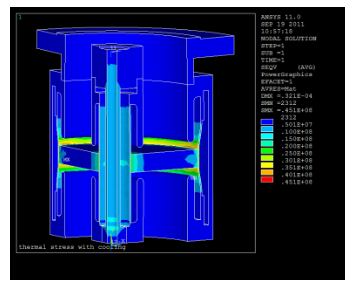

Figure 4: Simulated thermal stress distribution of RF window while 100 kW RF power passes through.

Another part requiring special cooling is the antenna loop. The RF heating on it is estimated to be 80 W while 100 kW transmission power passes through. An independent cooling circuit is adopted. In order to assure sufficient cooling, a two-way cooling channel is designed inside a race track-shape antenna loop. As can be seen in Fig. 5, with 0.4 L/min cooling water, the estimated maximum temperature increasing is below 10 ℃ at the operation power level of 80 kW.

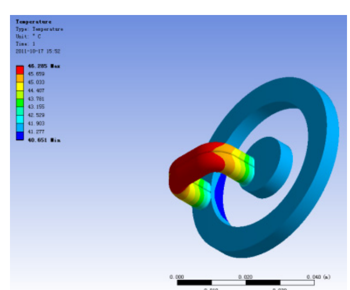

Figure 5: Simulated temperature distribution at the power level of 80 kW with a 0.4 L/min cooling water.

ESTIMATION OF EXTERNAL Q

The coupling is very sensitive to the area of the antenna loop. Since the dimension of the coupling port and the impedance of the coaxial line are fixed, the coupling area is only determined by the penetration depth of the antenna loop “h”. So the coupling design focuses on optimizing “h” to satisfy the optimum external quality factor Q_e.

Since the calculation of a 4.8 m long RFQ cavity is time-consuming, a simplified short model with 1/24 length of the real RFQ cavity is used to calculate the coupling. The calculated coupling coefficient β versus the penetration depth of the antenna loop “h” by MWS code is shown in Fig.6. When “h” is about 8 mm, the optimum coupling is achieved.

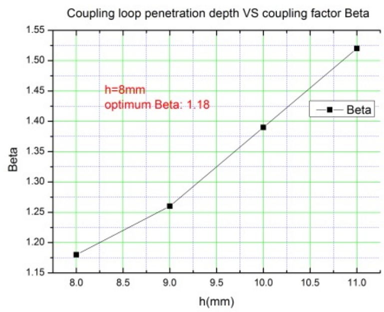

Figure 6: The calculated coupling factor under different coupling antenna loop penetration depth.

FABRICATION AND HIGH POWER TEST

Two window and inner conductor assembly shown in Fig.7 were fabricated in July 2012. Some key components fabrication proved particularly challenging. For the doorknob, it proved difficult to spin a copper plate of 1 mm to form the inner doorknob-shape component with a large diameter of 510 mm. So pressing was used for the inner doorknob forming. The location of the end-plate of the WR2300 waveguide was adjusted carefully before welding to get a good impedance matching. RF window is the most critical component. The window brazing is very difficult due to its complex structure. The brazing procedure was optimized to improve the brazing quality and reduce the number of the ceramic thermal cycling.

Figure 7: Fabricated window and inner conductor assembly for China ADS inject-I RFQ input coupler.

Since the maximum power transferring capability of the input coupler usually depending on the RF window, the two fabricated window and inner conductor assemblies were received high power test in August 2012. In the first step, all components were rinsed with pure water carefully in a class 100 clean room (Fig.8). Then the coupler was assembled onto the high power test stand, which consists of a pair of back to back couplers, one connected waveguide, vacuum system and monitoring system (Fig.9). A maximum of 100 kW CW RF power in TW mode has been reached after 50 hours conditioning, which can satisfy the RFQ requirement well.

Figure 8: Pure water rinsing was processed in clean room prior to test.

Figure 9: The window and inner conductor assembly are under high power test.

SUMMARY

A high power input coupler for China ADS inject-I RFQ has been developed. Two prototypes of the window and inner conductor assemblies have been fabricated and received high power test. The prototypes were tested up to 100 kW CW RF power mode in traveling wave mode. The whole input coupler will be fabricated, assembled on the RFQ cavity and tested in June 2013.

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