# Design of the new couplers for C-ADS RFQ *

SHI Ai-Min(石爱民)[1] SUN Lie-Peng(孙列鹏)[1;1)] ZHANG Zhou-Li(张周礼)[1] XU Xian-Bo(徐显波)[1] SHI Long-Bo(施龙波)[1,2] LI Chen-Xing(李晨星)[1,2] WANG Wen-Bin(王文斌)[1]

[1] Institute of Modern Physics, Chinese Academy of Sciences, Lanzhou 730000, China
[2] University of Chinese Academy of Sciences, Beijing 100049, China

**Abstract:** A new special coupler with a kind of bowl-shaped ceramic window for a proton linear accelerator named the Chinese Accelerator Driven System (C-ADS) at the Institute of Modern Physics (IMP) has been simulated and constructed and a continuous wave (CW) beam commissioning through a four-meter long radio frequency quadruple (RFQ) was completed by the end of July 2014. In the experiments of conditioning and beam, some problems were promoted gradually such as sparking and thermal issues. Finally, two new couplers were passed with almost 110 kW CW power and 120 kW pulsed mode, respectively. The 10 mA intensity beam experiments have now been completed, and the couplers during the operation had no thermal or electro-magnetic problems. The detailed design and results are presented in the paper.

**Key words:** coupler, RFQ, ceramic window, S parameter

**PACS:** 29.27.Bd, 52.65.Rr, 41.20.cv **DOI:** 10.1088/1674-1137/39/4/047004

## 1 Introduction

Since 2011 the Chinese Accelerator Driven System (C-ADS) project has been carried out in order to solve the nuclear waste disposition and energy shortage crisis [1]. According to the plan the goal of the project is to build a 25–50 MeV proton LINAC by 2015 whose upstream is a 2.1 MeV four-vane radio frequency quadruple (RFQ) operating in continuous wave (CW) mode [2].

Considering the lack of experiences for CW RFQ, a full-scale one-meter prototype cavity was fabricated and measured in the last two years. Simultaneously, a matching 30 kW coupler was also simulated and tested on the prototype cavity [3]. The results of conditioning or commissioning can help us to promote the coupler design and complete its fabrication for the real four-meter RFQ cavity of the C-ADS project. As a result, the 30 kW coupler for the prototype has been modified three times to avoid thermal breakdown during the RF power conditioning in 2013.

After the prototype operation, the new RFQ couplers for the C-ADS project with a quarter-wave cooling port for the thermal consideration, based on a 6 1/8 inch coaxial waveguide, was designed for the CW operation in 2014. The cooling channels are installed into the loop antenna, inner and outer conductor. The optimized $S$ parameter is better than −35 dB and the effect from the ceramic window is suppressed to the minimum. The ceramic window was designed according to the RF and brazing situation. The thermal and antenna simulation have been considered.

## 2 Specification of couplers

Since the many experiences from previous prototype designs and power experiments, the new two couplers were also optimized in the $S$ parameter several times. In order to better accelerate the proton beam, is necessary to handle the over-coupling configuration [4] with beam loading. Thus the specification of the coupler is as follows:

The simulation was mainly optimized on the $S$ parameter at the first time design resulting from the special structure of the ceramic window which can minimize the line impedance effect of ceramic into the coaxial line and decrease the difficulty of brazing. At the beginning of 2014, two couplers were completed by the Kelin Corporation in Shanghai. The observation port and ARC monitor port were also placed in the coupler whose structure is shown in Fig. 1.

Received 25 July 2014
* Supported by Strategic Priority Research Program of Chinese Academy of Sciences (XDA03020500)
1) E-mail: sunlp@impcas.ac.cn

Table 1. Target performance.

| requirement | target value | comment |
|---|---|---|
| nominal frequency | 162.5 MHz | ±1 MHz |
| duty cycle | 100% | pulsed mode possible |
| max. transmitted power | 60 kW | full reflection to be withstood on tetrodes AMP. |
| max. reflected power in operation | 31.5 kW | over-coupling (10 mA proton beam) |
| line impedance | 50.0 Ω | RF network impedance |

Fig. 1. (color online) The 60 kW coupler after fabrication.

## 3 Engineering design of couplers

Simultaneously, sufficient cooling channels were added to the inner conductor to decrease the copper deformation from the higher power (the design power reaches up to 120 kW which means more than 60 kW on every coupler). Fig. 2 shows the structure of the new 60 kW coupler.

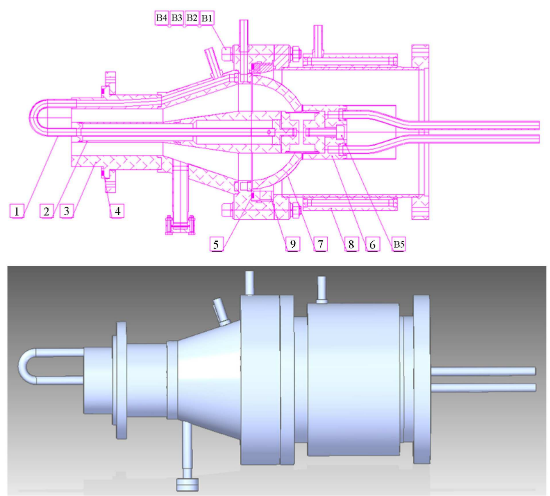


Fig. 2. (color online) Mechanical design of the 60 kW coupler.

For the regular coupler design, the electro-magnetic analysis and thermal calculation are the most important simulations. Considering the thermal breakdown of the previous prototype coupler, the new couplers were focused on the better cooling and $S$ parameter design.

### 3.1 Coupler matching port

An extra quarter wave part of EIA 6 1/8” waveguide was designed to connect with the coupler to improve the thermal situation [5]. The length of it can be confirmed by CST software or something else. The S parameter reached up close to −40 dB. The sizes and calculation are presented in Fig. 3.

For an input power of 60 kW in Fig. 2 and Fig. 3 structure, the total RF losses of 99 W in Fig. 2 coupler and 59 W in Fig. 3 were evaluated using 1-$P$11-$P$21, respectively [6].

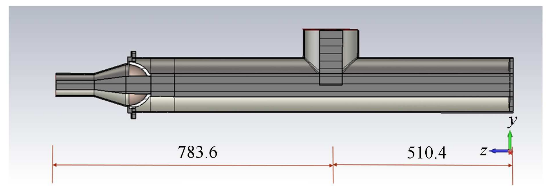


Fig. 3. (color online) The specific size of the matching port.

### 3.2 The antenna loop

The antenna loop was also simulated in the RF analysis software whose thermal distribution was presented in Fig. 4 (the shape of the loop was not the same as the design one because of the bending difficulty).

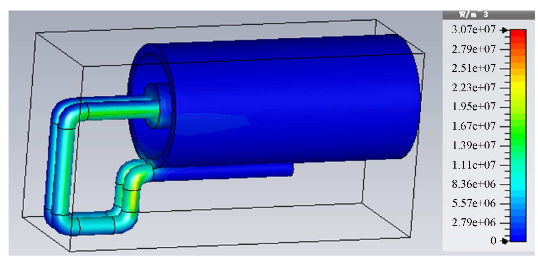


Fig. 4. (color online) The thermal distribution on the antenna loop.

When the high power is put into the coupler, the diameter of the cooling channels will be a compromising consideration, for instance, too small a diameter will increase the power loss along the loop resulting in serious deformation of the loop antenna. On the other hand, too large a one will raise the ratio of the loop area to RFQ that impacts field distribution into cavity. For a loop antenna part in RFQ, it was calculated to be 46 W using the coupling condition of $\beta$=1, where the coupling factor $\beta$ is defined as the external RF power by the ratio with the power in the RFQ inside, including RFQ wall loss and the beam power [7].

### 3.3 Thermal analysis

Due to the high power transmission through the coupler, the RF loss is a critical factor for the strong skin effect and dielectric insertion, especially for the high intensity beam as the over-coupling situation will increase the reflection power, which may have a risk of thermal damage on the ceramic window. The thermal results are also shown in Fig. 5. Since for the ceramic window, $AL_2O_3$ ($\varepsilon_r$=9.8, tan$\delta$=6×$10^{-4}$) was considered, the RF loss and related thermal situation were optimized gradually to minimum.

Simultaneously, the thermal simulation on the whole structure was also completed, which is shown in Fig. 6 and almost 70° temperature difference is within an acceptable limit.

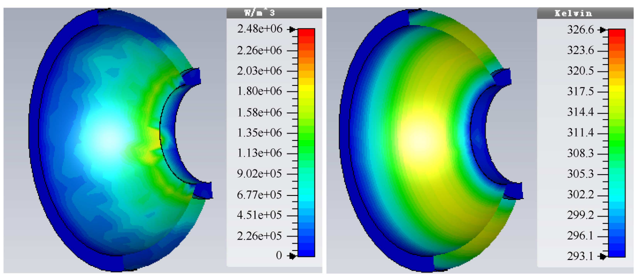


Fig. 5. (color online) The thermal simulation of the ceramic window. (over-coupling).

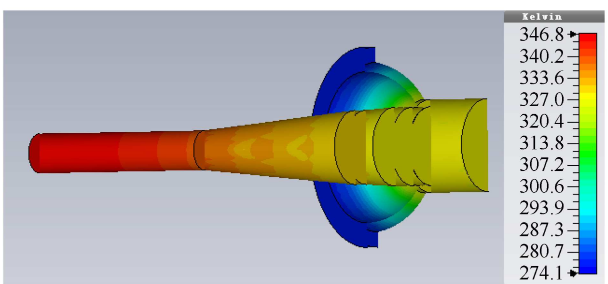


Fig. 6. (color online) The thermal simulation for the whole structure.

## 4 Summary

Due to the lack of the measurements of materials we have to reference manufacturer data, the specific hypotheses and results are given in Table 2 and Table 3. For the C-ADS RFQ linac, the engineering design of the RF input coupler was carried out. In the design, RF properties and RF power dissipation were evaluated by Microwave Studio (CST code), and the coupling factors were measured on a real cavity.

Table 2. Calculation parameters.

| materials | values |
|---|---|
| copper as inner/ | electrical conductivity |
| outer conductor | 5.8×$10^7$S/m |
| alumina ceramics | $\varepsilon_r$=9.8 (@162.5 MHz) |
| as RF window | tan$\delta$=6×$10^{-4}$(@162.5 MHz) |
| polyethylene as | $\varepsilon_r$=3.5 (@162.5 MHz) |
| Support disk | tan$\delta$=3×$10^{-3}$(@162.5 MHz) |

Table 3. Calculation results (@162.5 MHz).

| RF coupler model | $P_{11}$(%) | $P_{21}$(%) | 1-$P_{11}$-$P_{21}$(%) |
|---|---|---|---|
| without quarter-wave port | 0.0852 | 99.75 | 0.1648 |
| with quarter-wave port | 0.0617 | 99.84 | 0.0983 |

From these results, an RF input coupler design with three cooling channels, based on a 6 1/8 inch coaxial transmission line, was decided for CW operation mode. During RF power conditioning, a special two-port over-coupling configuration was applied.

As the newest development of couplers in IMP, two sets of couplers with bowl-shaped ceramic windows are designed by the RFQ group with complete intellectual property rights. The conditioning and beam commissioning process have already proved that the RF and structural design meets the requirements of the LINAC operation. Now, while CW mode power is close to 110 kW, the 10 mA beam has been detected and measured at the downstream diagnostic devices (the accelerated voltage has been fixed at 65 kV) whose measured results agree well with the original RFQ design, including beam intensity, transfer efficiency, emittance, and so on.


### References

1 TANG J Y et al. Conceptual Physics Design for the China-ADS LINAC. Proceedings of PAC2013. Pasadena, CA USA, 2013. 1397–1399

2 ZHANG Z L, HE Y, SHI A M et al. Design of a Four-vane RFQ for CHINA ADS Project. Proceedings of LINAC2012. Tel-Aviv, Israel. THPB039. 2012

3 SUN L P et al. Engineering Design of the RF Input Couplers for C-ADS RFQ. Proceedings of IPAC2014. Dresden, Germany. THPI049. 2014

4 Naito F et al. Input Coupler of the J-PARC DTL, LINAC'12. Israel, Sep.2012, TUPU099, 2012. 690–692. http://www.JACoW.org

5 Sunao Maebara, Antonio Palmieri, Paolo Mereu et al. Nuclear Instruments and Methods in Physics Research, 2008, **592**(3): 171–179

6 Maebara S et al. Design of an RF input coupler for the IFMIF/EVEDA RFQ LINAC. Proceedings of IPAC2010. Kyoto, Japan. THPEA020. 2010

7 OUYANG H P, QIAO J M, FU S N et al. High Power and Particle Beams, 2004, **16**(1): 117–120 (in Chinese)