

DESIGN OF A FOUR-VANE RFQ FOR CHINA ADS PROJECT*

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Abstract

A four-vane RFQ accelerator has been designed for the ADS project which has been launched in China since 2011. As one of the two front ends of C-ADS LINAC, the RFQ works at a frequency of 162.5MHz, accelerating the proton beam from 35keV to 2.1MeV. Due to the CW (continuous wave) operation mode, a small Kilpatrick factor of 1.2 was adopted. At the same time, Pi-mode rods are employed to reduce the effect of dipole mode on quadrupole mode, and cavity tuning will be implemented by temperature adjustment of cooling water. Beam dynamics design, RF cavity design and thermal analysis all will be presented in the paper. Some fabrication test of the RFQ cavity will be described, too.

INTRODUCTION

All the countries in the world are confronting energy problems during the process of economic growth and society development nowadays, on one hand more and more energy is required to maintain modernized human life, on the other hand the earth's resources are limited. Although it can help solve the problems, nuclear energy has some drawbacks. First it is not absolutely safe, nuclear radiations caused by accidents happen occasionally; Secondly, management of nuclear waste is difficult [1]. However, the concept of ADS (accelerator driven system) proposed by C. Rubbia and his group has made nuclear energy much more safe and efficient [2]. It makes nuclear reaction controllable and transforms long-lived transuranic elements from conventional

nuclear reactors to short-lived ones while producing electricity at the same time. Due to the advantages of ADS and more and more energy demands, China has launched the ADS project in 2011.

There are two front ends of the linear accelerator for the C-ADS project (as shown in Fig. 1), while IMP (Institute of Modern Physics) is responsible for injector2. The RFQ of injector2 will use the four-vane structure because of the CW operation mode. The frequency of injector2 is 162.5MHz, which will lead to a big size of the RFQ cavity and bring some challenges to the fabrication. Here the design of the RFQ will be presented.

BEAM DYNAMICS DESIGN

The RFQ of C-ADS injector2 is designed to accelerate proton beam from 35keV to 2.1MeV which can lead to small neutron production and material activation [3], and main parameters are listed in table 1. The frequency of 162.5MHz is chosen in order to decrease the power loss density of the cavity. The inter-vane voltage is 65kV, which can well reduce the probability of discharge. The twiss parameters and emittances of output beam are required to be less than 1.5, 0.33 π mm mrad and 1keV ns respectively, table 1 shows all these requirements are met. Because the cavity is 420.8cm long, it will be equally divided into four modules when fabrication.

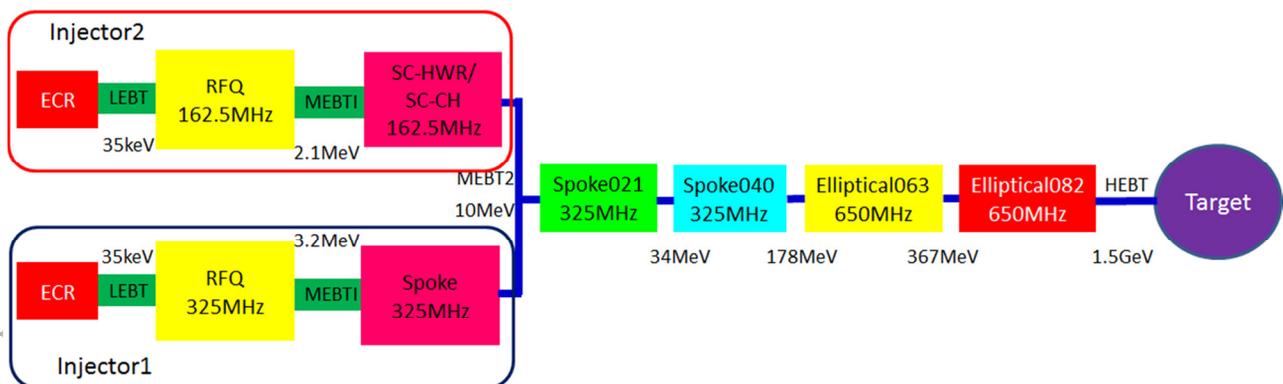


Figure 1: Layout of C-ADS driver accelerator.

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Table 1: Main Parameters of C-ADS Injector2 RFQ

Ion species	Proton
Frequency [MHz]	162.5
Input /Output energy [MeV]	0.035 / 2.1
Current [mA]	15
Input Emittance (nrms) [π mm mrad]	0.3
Output trans. Emittance (nrms) [π mm mrad]	0.31
Output long. Emittance [keV ns]	0.92
$\alpha_{in} / \alpha_{xout}, \alpha_{yout}$	1.21/0.36,-0.3
Inter-vane voltage [kV]	65
Kp factor	1.2
Minimum aperture [mm]	3.2
Modulation	1-2.38
Synchronous phase [deg]	-90 - -22.7
Cavity length [cm]	420.8
Transmission efficiency [%]	99.6

RF DESIGN AND THERMAL ANALYSIS

The average aperture r_0 of the RFQ is 5.731mm, and the ratio of vane-tip radius ρ to r_0 is 0.75. Four-vane structure is adopted so that cooling channel can be easily configured. A slice of 1mm of the structure (see Fig. 2) was calculated by the CST MWS code [4], and it shows the frequency is 162.31MHz and Q value is 16890 when the distance between cavity wall and beam axis is 177.1mm.

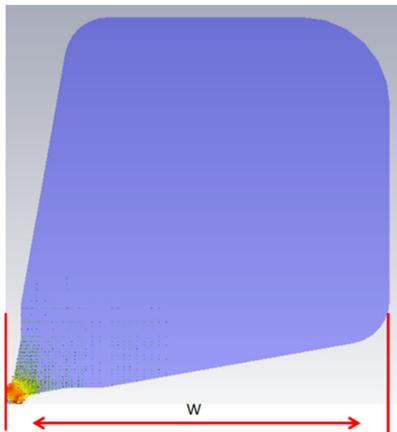


Figure 2: Transverse profile of C-ADS injector2 RFQ.

One feature of the RFQ is that it utilizes pi-mode rods (as shown in Fig. 3) to increase the span between the operation frequency (quadrupole) and adjacent dipole mode frequency, results demonstrate that the dipole mode frequency will shift from 157.6MHz to 181.7MHz when pi-mode rods with interval of 262.5mm are inserted into the RFQ cavity.

Full model of C-ADS injector2 RFQ is shown in Fig. 3, it has 16 pairs of pi-mode rods and 80 tuners. Calculation results reveal that Q value and full power loss of the whole cavity are 13337 and 91kW respectively when its frequency is 162.489MHz.

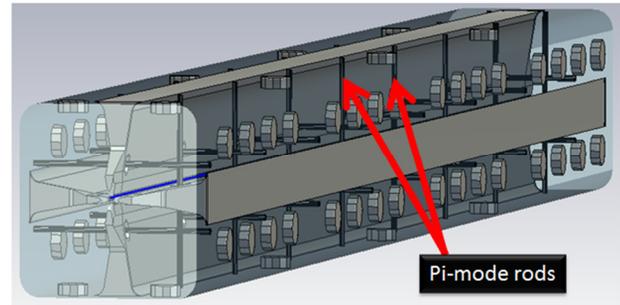


Figure 3: Full model of the C-ADS injector2 RFQ.

Thermal analysis was done with the ANSYS code [5] to study the cavity cooling issues and to know about how to tune the cavity by adjustment of cooling water temperature. Layout of cooling channels is displayed in Fig. 4, there are total eight cooling channels (diameter is 12mm) in the wall and four in vanes for each module. Temperature of the injecting cooling water was assumed 20°C, and velocity of the cooling water was 2.29 meter per second. Basing on the data mentioned above, temperature distribution of the cavity is shown in Fig. 4, and the relationship between cavity shifting frequency and cooling water temperature is -8.7kHz/°C for vane and 6.1kHz/°C for wall respectively.

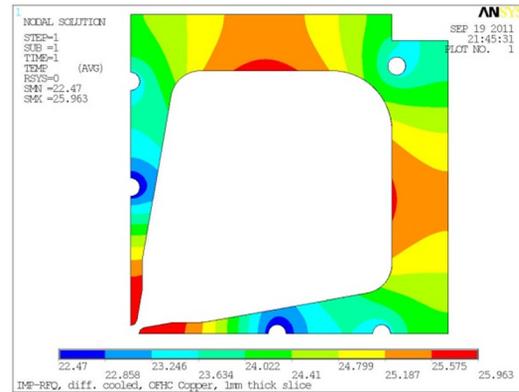


Figure 4: Temperature contour of the C-ADS injector2 RFQ.

FABRICATION TEST

The four-vane C-ADS injector2 RFQ has a big size (length of each side is bigger than 400mm) because of its low frequency. That brings some challenges to the fabrication of the cavity because we do not have any experiences in building such a big bulk. Therefore some fabrication tests are carried out, including flying cutter (as shown in Fig. 5), brazing of the bulk and machining

of a single vane (as shown in Fig. 6). Measurement results with CMM demonstrate that machining error of the cutter is controlled within $\pm 11\mu\text{m}$, which meets the machining requirement of vanes. Some problems are met during the brazing test, one reason is that the brazing clamp cannot fix the vanes properly, the other is vacuum oven was employed instead of hydrogen oven. Therefore a new hydrogen oven has been purchased, and new clamps are being designed. Besides the above tests, building of a half long module is being underway.

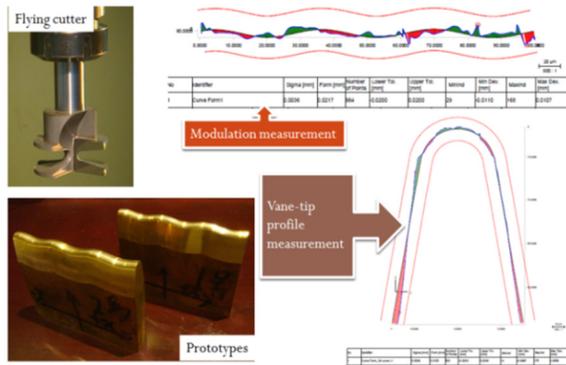


Figure 5: Flying cutter test.

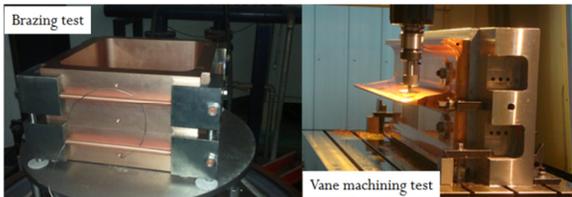


Figure 6: Brazing test and vane machining test.

CONCLUSION

A four-vane RFQ has been carefully designed including beam dynamics design, RF design and thermal analysis. The size of the RFQ is big owing to its low frequency which brings some challenges to the building of the cavity, and some fabrication tests have been done to make sure the real cavity can be built successfully. At present a half long module is being manufactured, and the cooling water system of the cavity is also being built. The real RFQ cavity is expected to be fabricated in next month.

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