DEVELOPMENT OF A 3.5MEV RFQ FOR ADS AT IHEP

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Abstract

ADS technology is under study in China for the purpose to provide a new option for the development of nuclear power station, which is going to play a more important role in our newly increased power resources to meet the demand of the rapid economy growth. In an ADS basic research program supported by Chinese government, a long-pulse intense-beam RFQ accelerator will be built at IHEP, Beijing, as the means to master the key technology in a CW RFQ. At present we have finished the design of the RFQ with pulse beam current of 50mA, output energy of 3.5MeV and length of 4.7m with two segments coupled by a resonant coupling cell. A technological copper model cavity of 1.2m long has been machined. The RF power supply of 352.2MHz, 1.2 MW has been installed. In this paper, we will report the R&D activities on the RFQ, including the beam dynamic design, the copper model manufacture and measurement and the RF power supply.

INTRODUCTION

A basic research program for ADS was lunched in China for clean nuclear energy production. ADS is regarded as a competitive option for nuclear power generation to meet the increasing demands on energy resource to sustain the rapid economic development in China. To approach to a CW beam, a high duty-factor RFQ, as the first step, was built at IHEP supported by this program. Some R&D activities have been performed to pave the way for the final fabrication of the RFQ. In this paper we will give an outline of the RFQ in the next section. Then the work on the technology model cavities is introduced. The fourth section will briefly present the setup of the high-power RF supply. Finally we will introduce our study on the dipole rod effect.

OUTLINE OF THE RFQ

The four-vane type RFQ accelerates a proton beam from an ECR ion source of 75keV to the energy of 3.5MeV. Fig.1 depicts the beam dynamics in the coupling cell simulated by LIDOS.RFQ codes [1]. The major parameters of the RFQ are listed in Table 1. More details on the beam dynamic design and the RF cavity design can be found in reference [2].

This RFQ has a length of about 5 times wavelength and hence the longitudinal field stability is a series issue. To address it the resonant coupling option proposed by L.Young [3] is adopted. The 4.7m-long accelerator is separated into two segments and each segment consists of two technological modules. The dipole rods on the both end plates and the coupling plate are applied to move the dipole mode far away from the operating mode. As a high-duty machine, water cooling on both the vane and wall is necessary to keep the thermal stability. There are 20 cooling channels on the cavity body in each section. Four vane-wall pieces are brazed to form a cavity for both RF and vacuum seals. On each module there are 16 tuners distributed on the 4 quadrants. There are 8 vacuum ports on both the first and fourth modules, respectively. Eight RF feed ports are located on the second and third sections and the RF-power is coupled into 4 quadrants evenly to keep the field balance among them. Only half of the power ports are used for the present 6% duty operation If necessary to operate at a high duty factor in future, other four ports will be used.

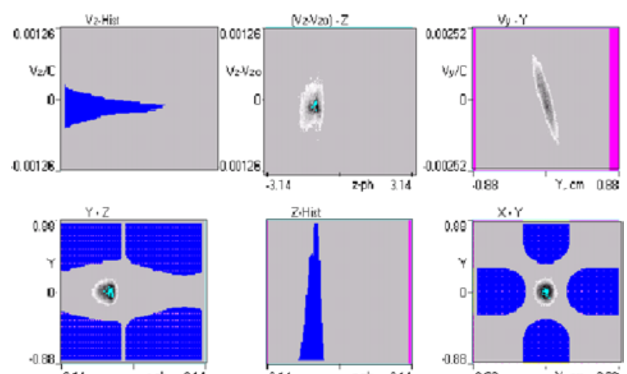

Figure1: LIDOS.RFQ simulation of beam bunch just ahead of the coupling gap.

Table 1: RFQ major parameters

Input Energy	75keV
Output Energy	3.5MeV
Peak Current	50mA
Structure Type	4 vane
Duty Factor	6%
RF Frequency	352.2MHz
Maximum E_s	33MV/m
Beam Power	210kW
Structure Power	420kW
Total Power	630kW
Total Length	4.75 m

R&D OF TECHNOLOGICAL MODEL

As the high accuracy fabrication of the RFQ cavity is a very tough issue for us, we started with some technological models before the manufacture of the formal cavity.

A short OFEC copper RFQ section of 0.42m long was fabricated with fine machining. It has two major purposes to make this model: one is to demonstrate the high-accuracy machining and another is to verify the brazing deformation. The machining tolerance reaches ± 20μm on the vane tip and cavity wall measured on a CMM. There are two RF tuners with pickups and two vacuum ports on the four quadrant walls respectively. On this short cavity all cooling channels for cavity walls, vanes and vacuum ports are drilled and connected with pipes, as shown in Fig. 2.

Figure 2: A Short RFQ technological model after final braze.

Figure 3: Bead-pull measurement setup for the field distribution analysis of the short technological model.

With two aluminum end-cells with undercut, we measured the resonant modes and field distribution by bead-pulling method in each steps: first assembly, second assembly before the first brazing for the four cavity pieces, after the first brazing, after the second brazing for the flanges and cooling-water pipes. Fig.3 shows the bead-pulling measurement setup. The measurement results indicate that there is a little frequency downshift after the first brazing, but a little up-shift after the second brazing, as listed in Tab.2. It shows the final frequency is 0.226MHz lower than that of the code simulation. Two LabVIEW codes were applied during the measurements. One was used to control measurement process and data acquisition via a GPIB-ENET/100 box. Another was used to analyze the collected data. The field distribution of the dipole modes along the cavity is plotted in Fig.4, which was measured after the final brazing. It indicates a dipole components of 3% exist in 1-3 quadrant.

Table 2: Operating frequency shift between brazing steps and comparison with the simulation.

Steps	f_Q(MHz)	δf_Q
Before 1st brazing	351.232	
After 1st brazing	350.955	-0.277
After 2nd brazing	351.119	+0.171
Simulation by code	351.345	-0.226

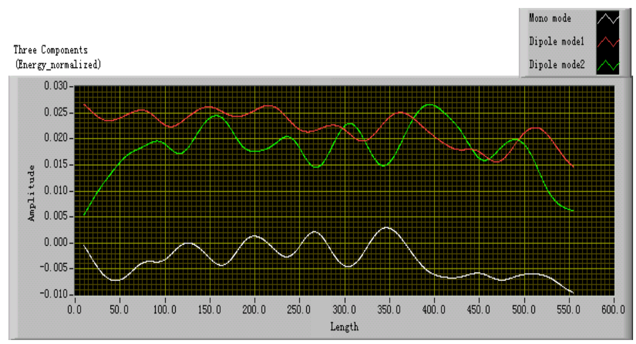

Figure 4: Dipole field distributions along the cavity after final brazing.

Another important technological model is a full length brazing cavity. There are two essential purposes for this model: drilling some long and small channels for water-cooling and brazing a full volume cavity.

The water-cooling channels are drilled on the vane and wall. There is a tight alignment requirement for these channels, especially the 2 channels on each vane. On the rough shape of the cavity pieces, the channels were drilled. At this step, we could not expect a very good alignment on each channel in the length of 1.2m, but it is possible to get the shift of each channel in the same direction and with almost the same amount. After a series of trials, we reached this goal. To apply this method, all the channels were drilled through the rough pieces from end to end. And then two plugs were used to cover the both ends of a channel, as shown in Fig. 5.

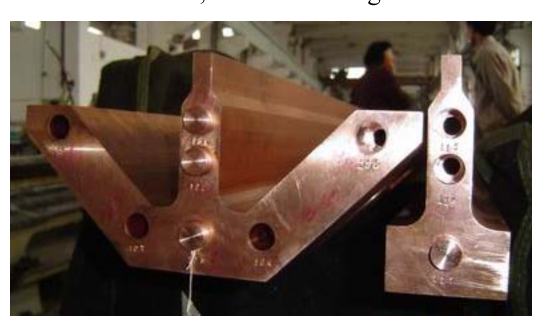

Figure 5: The water cooling channels of 1.2m long were drilled through the pieces and plugs were used to cover them on each end by brazing.

A full-size cavity was formed by brazing the four vane pieces together. Among the four pieces, only one was finely machined and the other three were only roughly machined. This cavity contains all of the flange ports in order to verify the furnace temperature's evenness in both radial and vertical directions. The stainless steel flange was first brazed with copper neck for the tuner port, or with the vacuum grid copper body. All of these flanges were then brazed onto the cavity after the four vane pieces had been brazed together. In Fig. 6 the up-left are the flanges of tuner port, the down-left is the vacuum grid body with the cooling-water channel covers, and the right is the 1.2 meter long brazing test model after the final brazing. Vacuum leak check demonstrates all of the brazing is vacuum tight. The leakage rate is 1.9×10^{-9} Torr *l*/s. The success of this model validates the design of the filler distribution, the machining accuracy of the brazing surface, the assembly of the four vanes with a proper and a balanced press force, as well as the adequate control of the brazing temperature.

Figure 6: The 1.2m long full size model for brazing test with tuner and vacuum flanges.

THE RF POWER SOURCE

The RF power source for the RFQ from CERN has been installed at IHEP. It was a CW RF power source of 352.2MHz/1.2MW, decommissioned from LEPII. The TH2098 klystron, modulator, HV power supply, Y-junction circulator, RF control system, dummy loads and water-cooling system have been connected, as shown in Figure 7.

Figure 7: The RF power system has been installed and connected.

We have fulfilled a difficult task to reconnect the control rack because a lot of cables were cut during the transportation from CERN to Beijing, and we have no any circuit diagram for the cables connection. The modulator from CERN worked in ramping mode for LEPII. To adapt to our RFQ square pulse mode at various duty factors, some necessary modifications of the modulator has been made. The monitors and protection system of the water-cooling system were added to the control rack. In addition to the equipments from CERN, we have designed and made two step-down transformers, as well as a set of MCB. Now the RF power source is ready for the first high power test on the dummy loads in this month. More details about the work on the source is described in reference [4].

STUDY ON THE DIPOLE ROD

The RFQ is azimuthally stabilized by the stabilizer rods. The rod's size and location in the quadrants were calculated by both 2-D and 3-D simulations, and the coupling cell geometry was also designed [5]. To demonstrate the design and to study the effect of the dipole rod, some RF measurements were performed on a copper model RFQ module. The measurement results in Fig. 8 indicate that the dipole rods have almost no perturbation to the frequency of the operating quadrupole mode (δf_{Q0}=-50kHz when rod length=15cm), and the tuning effect to the dipole mode is obvious when the rods length is longer than 10cm.

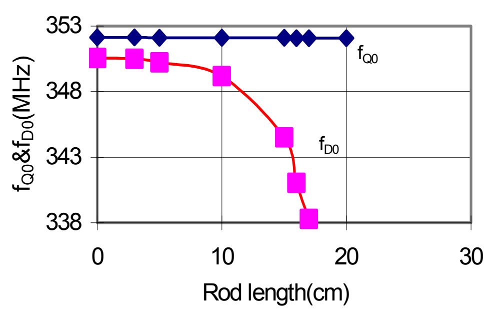

Figure 8: The measured dipole-rod effect on operating quadrupole mode and dipole mode.

ACKNOWLEDGMENTS

We are grateful to the great support on the RF power source from CERN. The fruitful collaboration with Shanghai Kelin Tech Co. and USTC Acc. Tech Co. Ltd. is highly appreciated.

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