

## DEVELOPMENT OF HIGH CURRENT 201.25 MHz DEUTERON RFQ ACCELERATOR\*

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### Abstract

The beam dynamics for a 201.25MHz 50mA 2.0MeV Deuteron RFQ accelerator with duty cycle of 10% has been further improved by using equipartitioned method. The RFQ structure, mechanical design, thermal analysis and its cooling method have been investigated. The tuning of RF cavity for the field and other parameters has been simulated. A new developed ECR ion source and its setup have been completed and tested. The LEBT for the injection of RFQ is under the construction, and the HEBT at RFQ exit for the further applications has been designed and to be constructed in the near future. All the development results will be presented in this paper.

### INTRODUCTION

Since 1980s, high current RFQ accelerators have been developed very quickly and widely used in many areas such as SNS[1], ADS[2], BNCT, Medical Cancer Therapy Project[3] and other large scale accelerating systems[4]. Most of RFQs for protons were operating around 350MHz or 425MHz to get shorter wave length and larger RF accelerating efficiency or effective shunt impedance by using four vane structures. RF amplifiers were mostly more expensive klystron amplifier. A new trend of RFQs for proton and deuteron is using four-rod structure to operate at the frequency around 200MHz[5]. It makes the possibility of post Drift Tube linear accelerators to operate at 200MHz with the injection energy lower as 400keV/u[6]. The amplifiers for the RFQ and DTL could also be much cheaper and compact tetrode amplifiers. The high current four rod RFQ has a better future especially on the antiterrorism of detection of plastic explosive material and compact BNCT facilities. This paper will introduce new development of high current four rods 201.25MHz 2MeV deuteron RFQ accelerator at Peking University.

### BEAM DYNAMICS SIMULATION

Our destination is to design a deuteron RFQ accelerator with output deuteron energy 2MeV and operating frequency of 201.25MHz. The criteria for the deuteron RFQ simulations are listed as the following:

- RFQ cavity length should be as short as possible to be sure the peak RF power dissipation per unit length less than 100kW. The TH781RF amplifier could deliver 400kW with 10% duty cycle and pulse duration of 1ms. About 100kW peak power should be for the accelerated beam power.

- The beam transmission shouldn't be less than 90%. The energy of most lost deuterons should be less than 100keV to avoid D-D reaction, the RFQ electrodes and the RF cavity being neutron radioactive.
- Try to keep the inter-vane voltage and kilpatrick number less than 75kV and 2.0, respectively. This is very effective to save the RF peak power and be sure the cavity operation safety.

Based on the above considerations, the experience on PARMTEQM RFQ beam dynamics simulations[7], especially a new equipartitioned design method[8] and self developed new code RFQDYN, the simulation fits the design destination. The simulation results are shown in the table 1. Beam transportation along the axis is shown in the figure 1. The transmission efficiency would be better if the length could be longer. The input and output phase space diagrams are shown in figure 2.

Table1: The simulated deuteron RFQ parameters

Input energy /keV	50.0
Output energy /MeV	2.0
Beam current /mA	50mA
Frequency /MHz	201.25
Inter vane voltage /kV	74
Cavity length /cm	270
Cavity diameter /cm	30
Accelerating cells	181
Maximum modulation	1.8
Aperture radius /mm	3.78
Synchronous phase /°	-29.8
$\epsilon_{x_{in}}, \epsilon_{x_o}$ (norm.rms)	0.2mmrad
$\epsilon_{y_{in}}, \epsilon_{y_o}$ (norm.rms)	0.2mmrad
$\epsilon_{z_o}$ (norm.rms)	0.14 MeV-deg
RF dissipation /kW	270
Beam power /kW	100
Total power /kW	370kW
Transmission	93.6%

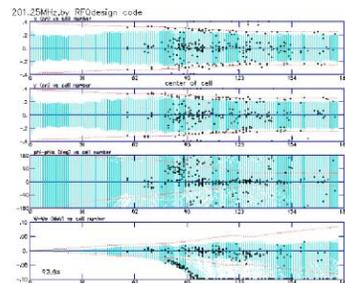


Figure 1: Beam transportation along the axis.

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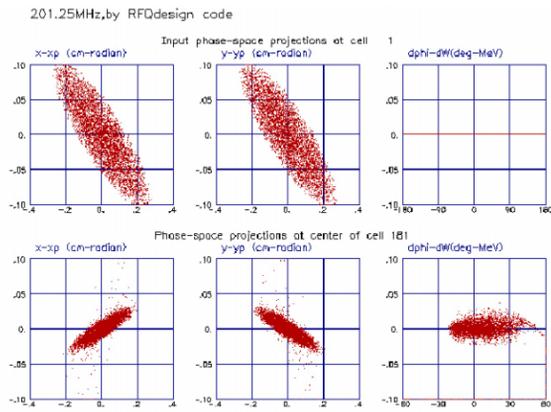


Figure 2: Input and output phase ellipses.

### THE RFQ STRUCTURE DESIGN

The RFQ inner structure design is composed of mini-vane electrodes (figure 3), 32 supporting plate stems (figure 3), and mounting ground plate. They are all water-cooled. The electrodes will be divided to three segments and water-cooled separately. That is the reason why the supporting stems 11,12,21,22 are much thicker than the other stems. The water-cooling tubes are silver welded with connection copper blocks and pass through the supporting stem to the cavity outside. There isn't any water sealing and vacuum sealing o-ring inside the cavity. So the RF connection can be ensured to have RF power dissipation as less as possible.

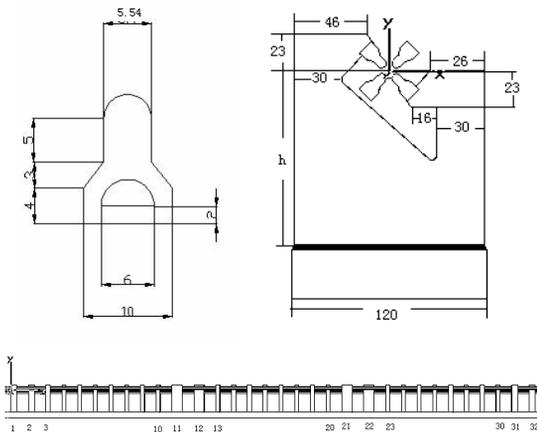


Figure 3: Mini-vane electrodes, electrode supporting stems, and mounted inner structure.

The tuning of the cavity has been done by the initial electromagnetic field simulation. The frequency can be adjusted by the mounting height  $h$  of the electrodes. There are also four stub tuners along the cavity, they can adjust not only the field distribution along the axis, but also the cavity resonating frequency. The supporting stems 11,12,21 and 22 are also very useful to balance the field distribution along the axis. It will make the field and the frequency go up. Another way to change the field and the frequency is putting some additional copper blocks between supporting stems. There are different results

when the tuning is done in such way. At both ends of the cavity, it will make the field at both ends of electrodes go down. But if it is put in the middle of the cavity, it will make the local field go up. The changing of frequency is similar to go up no matter where it is put. This is very sensitive tuning method but it increases additional RF power dissipation. So its RF contacting is very important.

From the field simulation, the RF power dissipation for the different components is shown in figure 4. The more detailed power density distribution can be delivered to the code ANSYS to do the thermal analysis. The thermal analysis shows the water temperature rising at both ends of electrodes is only about  $4.5^{\circ}\text{C}$ , the deformation of the electrodes is very small. Because the supporting stems dissipate 69% of total RF dissipation power 270kW, the figure 5 shows the deformation of the stem.

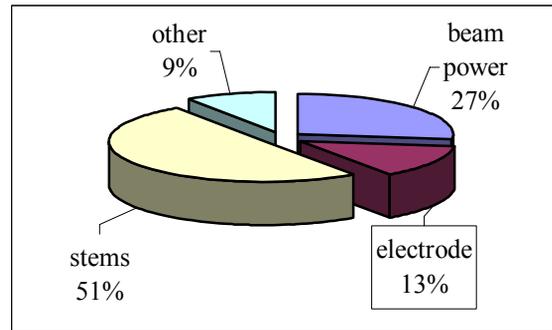


Figure 4: Power dissipation.

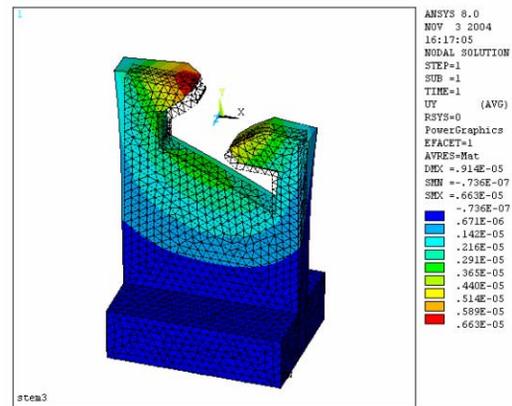


Figure 5: The maximum water temperature rising is about  $4.5^{\circ}\text{C}$ , deformation in vertical is about  $7\mu\text{m}$ .

### RF AMPLIFIER AND RF FEEDER

400kW amplifier with TH781 hypervaportron tetrode have been tested successfully with 1% up to 8% duty cycle and repetition frequency of 100Hz [9]. The 80kW water cooling system composed of two 40kW refrigerators,  $1.6\text{m}^3$  de-mineral water container, three water pumps with maximum  $8\text{m}^3/\text{h}$  water flowing has been completed and run nicely. It is suitable for providing the cooling water for the cavity and RF amplifier. The water inlet temperature could be handled in the range of  $\pm 2^{\circ}\text{C}$ . The controlling of cooling water system is made of

Siemens 200 PLC shown in the figure 6. The RF magnetic feeder for the deuteron cavity is also water cooled and shown in figure 7. The loop area is about  $15\text{cm}^2$ .

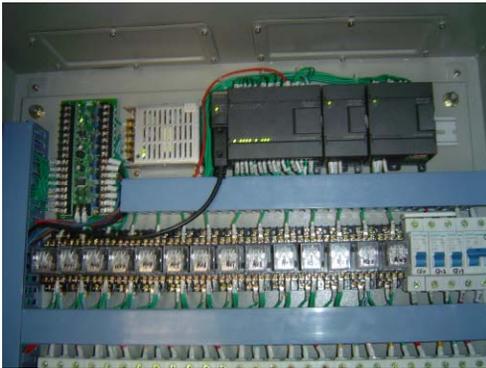


Figure 6: Siemens 200 PLC Controlling of 80kW cooling water system.

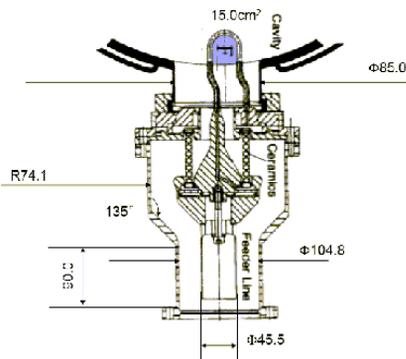


Figure 7: RF magnetic feeder.

### ECR ION SOURCE AND LEBT

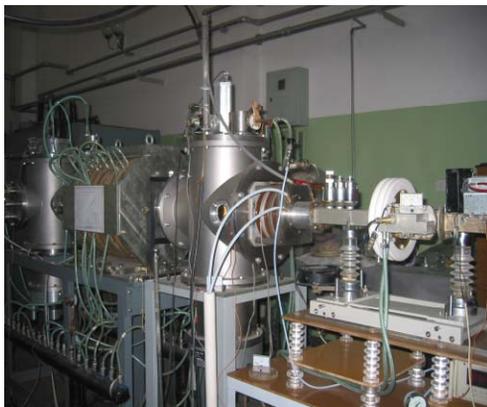


Figure 8: ECR ion source and LEBT.

The microwave power supply for an ECR ion source can operate in CW and pulse modes. It is operating at 2.45GHz and can deliver maximum 2kW to the discharging chamber with diameter of 50mm. Figure 8 shows ECR ion source cooled by oil and LEBT composed of emittance measurements, faraday cups, and 1500l/m turbo-molecular vacuum pump system and focusing solenoids. The vacuum for the LEBT is around  $6.6 \times 10^{-5}$  Pa. With pulse mode, more than 100mA proton beam

with proton ratio of 80% has been extracted at 50kV, the measured normalized rms emittance is about 0.2mmrad. The extraction for the deuteron will be done soon.

### CONCLUSION

A 201.25MHz 2MeV deuteron RFQ with 10% duty cycle and 100Hz repetition frequency has been launched. The beam dynamics simulation with a new equipartitioned design method has been further improved. The new design makes the cavity length shorter; the RF dissipation power is only about 270kW. The mechanical and rf structure design have been verified by the electromagnetic field simulation. The power dissipation for every component could be effectively cooled by a 80kW water-cooling system. Through the ANSYS analysis, the water temperature rising for the electrodes and the supporting stems is all less than 4.5°C. Water-cooling system can control the water inlet temperature be in the range of  $\pm 2^\circ\text{C}$ . The initial ECR ion source and LEBT tests show it is able to extract more than 100mA protons at 50kV with normalized rms emittance about 0.2mmrad. The deuteron extraction experiment will be done after the shielding improvements of working area. The HEBT will be further investigated by the demands of the application and to be constructed in the near future.

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