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# A Neutron Source Based on a 2 MeV Deuteron RFQ Accelerator

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## Abstract

A thermal neutron source based on a RFQ accelerator is being constructed at Peking University, which consists of a fast neutron source based on a RFQ accelerator and a moderator-collimator-shielding assembly. Fast neutrons are generated by deuteron-beryllium reaction. The deuteron beam is extracted from a 2.45 GHz ECR ion source and accelerated in RFQ to 2 MeV. The RFQ works at 201.5 MHz in pulsed mode. The designed peak deuteron current is 40 mA with a duty factor of 10%. The expected fast neutron yield is higher than $3\times10^{12}$ n/s. The main moderation material is polyethylene. Due to the higher γ ray yield of deuteron-beryllium reaction there is a layer of lead around the central moderator to shield the γ ray. Outside the lead a layer of polyethylene containing boron is used to attenuate the fast neutrons and to absorb the thermal neutrons.

## 1. Introduction

The neutron sources were used in many fields, such as neutron scattering, neutron radiography and tomography, neutron activation analysis, explosives and contrabands detection and so on. In addition to spallation neutron source, the neutron source based on radio frequency quadrupole (RFQ) accelerator or RFQ/DTL combination has been developed in recent years. The LENS (low energy neutron source), which is a project of proton RFQ/DTL accelerator driven neutron source, has been constructed in Indiana University [1]. Frankfurt University also launched a neutron source project based on the RFQ and IH-DTL complex [2]. This kind of neutron sources has smaller scale so it is more suitable to universities. A thermal neutron source based on a 2 MeV deuteron RFQ accelerator is being constructed at Peking University for this reason [3], which will be a component part of the PeKing University Neutron Imaging FaciliTY (PKUNIFTY).

The thermal neutron source of PKUNIFTY consists of ECR ion source, LEBT, RFQ accelerator, HEBT and target, and moderator-collimator-shielding assembly. The details about that neutron source will be presented below.

## 2. Thermal Neutron Source of PKUNIFTY

### *1.1 ECR Ion Source*

The permanent magnet ECR deuteron ion source is used in PKUNIFTY [4]. It has advantages of high ion current density output, high duty factor and stable performance. We have done many experiments of this type of ion source and got many good results [5]. The main parameters of deuteron ECR ion source are given in table I. There are two improvements on the new version of this ion source comparing with its predecessors. 1. An aluminum liner is inserted into the discharge chamber to reduce the radius of the chamber.

That is useful to increase plasma density and atomic ion fraction. 2. New electrodes with 90°cone apex angel are used to replace the flat electrode extraction system. This change can reduce the emittance of ion beam. The cut view is shown in figure 1.

Table I Parameters of ion source

| | |
|---|---|
| $D^+$ beam current | 50 mA |
| Energy | 50 keV |
| Duty cycle | 100 Hz |
| Pulse length | 1 ms |
| Emittance(norm rms) | <0.2π mm mrad |

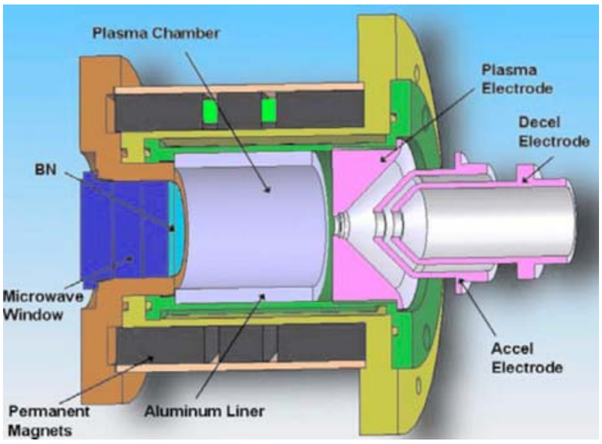



Fig. 1. Cut view of ion source

### *1.2 LEBT*

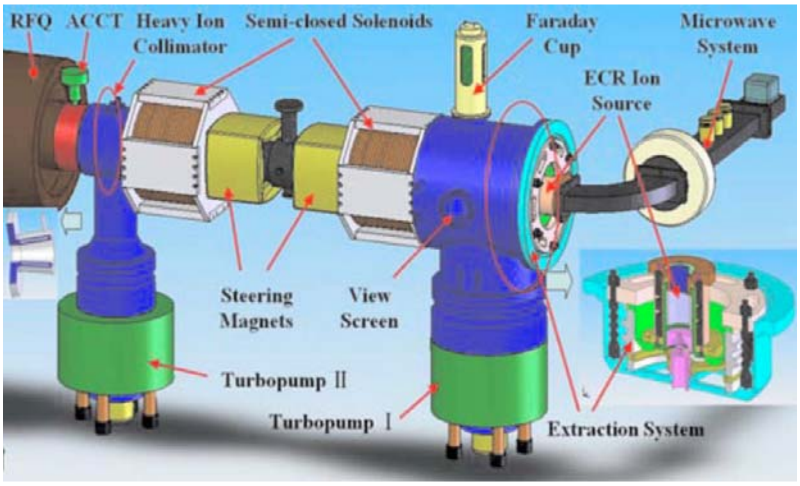



Fig. 2. Sketch of LEBT

The LEBT consists of two semi-closed solenoids, x and y direction steering magnets, faraday cup and ACCT current monitor. A sketch of the LEBT and ion source is given in figure 2. Two solenoids are more flexible than one solenoid for the beam match at the entrance of RFQ accelerator when beam extraction from the ion source is not in ideal condition. In order to reduce the space charge effect on beam transmission, the LEBT is designed as short as possible. The beam transmission of the LEBT is simulated with trace-3d program and the beam envelopes of design result are shown in figure 3.

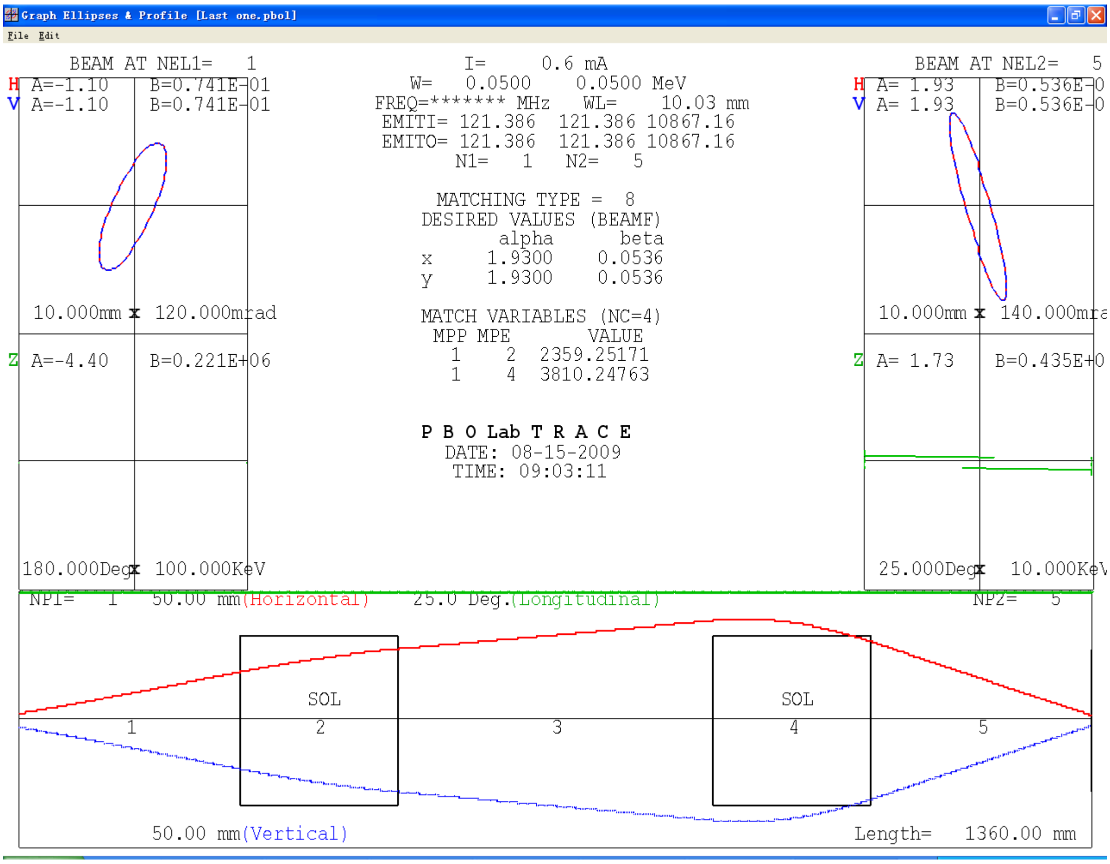


Fig. 3. Beam transmission envelope of LEBT

*1.3 RFQ Accelerator*

The RFQ accelerator is four-rod type mini-vane RFQ, which works at 201.25 MHz. We can use the tetrode amplifier at this frequency, so that accelerator system is more economic. At this frequency four-rod RFQ is more compact than four-vane RFQ, and the mini-vane structure can provide adequate cooling. In beam dynamics design, the energy of most lost particles is restricted below 100 keV, so that the radioactivity of the cavity can be restrained in lower level [6]. The RFQ cavity is designed by 3D electromagnetic simulation software. In the RF design, the RFQ cavity structure is optimized in order to increase the shunt impedance and flat the electric field along the beam axis [7]. The parameters of RFQ accelerator are listed in table II.

Table II RFQ parameters

| | |
|---|---|
| Working frequency | 201.25 MHz |
| Input energy | 50 keV |
| Output energy | 2 MeV |
| Output peak current | 40 mA |
| Max pulse width | 1 ms |
| Duty factor | 10% |
| Peak RF dissipation power | <270 kW |
| Electrode voltage | 70 kV |
| RFQ length | 2.7 m |

*1.4 HEBT*

Because the neutron hall space is limited, the high energy beam line is designed as short as possible. It consists of a triplet quadrupoles, an ACCT current monitor, two steering magnets, beam position monitor and a fast closing valve. The beam line layout is shown in figure 4. The beam line does not include bending magnet, so we design a small radius vacuum pipe behind the triplet to decrease the anti-direction neutron flux. The ideal beam envelopes are shown in figure 5. The target is 45 degree oriented to the beam direction, the diameters of beam spot on the target are both 3 cm in x direction and y direction.

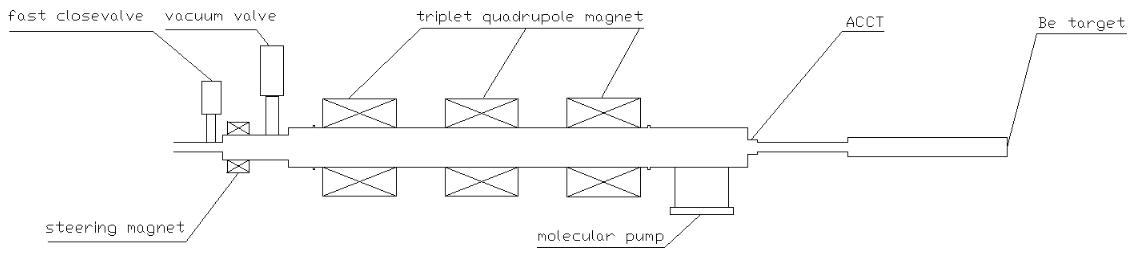
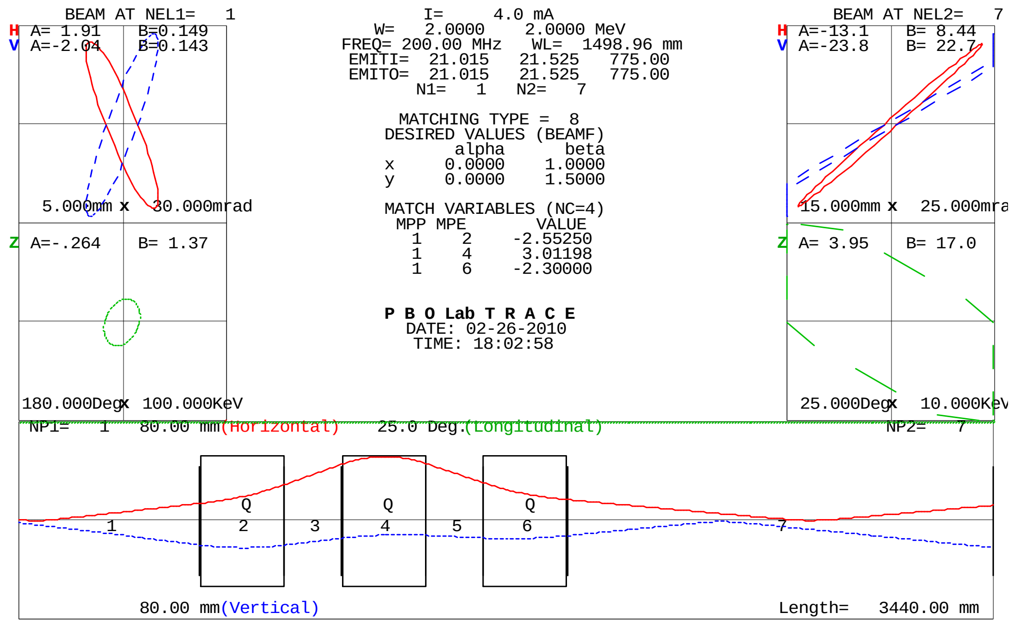



Fig. 4. Beam line layout of HEBT

Fig. 5. Beam envelopes of HEBT




*1.5 Target*

Neutrons are produced by deuteron beryllium reaction. In the target design two problems should be considered. Firstly the high current beam produces high power density on the target, so the cooling of the target should be carefully designed. Secondly the deuterium atom accumulation in the beryllium target can cause hydrogen embrittlement, so we should find the way to decrease the effect of hydrogen embrittlement. As the first stage, a 4 mm thick flat beryllium target is designed for the operation under an average power of 2 kW. In the future, we will design the high power target, which can be reliably operated at the average power of 8 kW.

*1.6 Moderator-collimator-shielding Assembly*

The neutron moderator collimator and shielding (MCS) assembly is shown in figure 6. The beryllium target was placed in the center of the MCS. Surrounding the target is the moderator-reflector, which consists of PE in the central part and water in the rest space. There are two layers of shield. Inner part is 8 cm lead, and outside is 40 cm boron doped PE. In order to improve Gd ratio and n/γ ratio, the collimator axis is at an angle of 90° to the deuteron beam direction. The aperture of the collimator is removable. It can be as large as 4 cm.

When the beam current is 4 mA, the fast neutron yield is higher than $3\times10^{12}$ n/s. If the aperture is 2 cm in diameter and the distance between the aperture and the imaging plan is 1 m, the neutron flux is about $6\times10^{5}$n/s, the Gd ratio is 1.6, and the n/γ ratio is $1.6\times10^{10}$ n/cm$^2$/Sv.

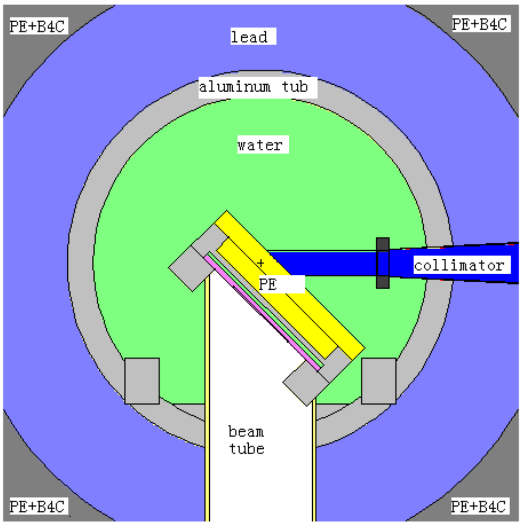


Fig. 6. sketch of moderator and shielding

## 3. Conclusions and Outlook

A compact neutron source based on 2 MeV RFQ accelerator is being set up at Peking University. The designed peak current of output deuteron beam is 40 mA with 10% duty factor. As the first stage a 2 kW beryllium target is going to be used and the 8 kW high power beryllium target will be developed in the near future. The rated fast neutron yield is $3\times10^{12}$ n/s, and the expected thermal neutron flux is higher than $5\times10^{5}$ n/s when L/D is 50. The whole facility will be installed and commissioned by the end of 2010.

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