DESIGN OF A DEUTERON RFQ FOR NEUTRON GENERATION

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Abstract

A 201.5 MHz 2.0 MeV deuteron RFQ accelerator for neutron generation has been designed. The general considerations, particle dynamics and RF structure design of the RFQ cavity are discussed. The progress of the studies on ion source, LEBT and RF transmitter are presented.

INTRODUCTION

Neutron has been widely used in various fields. In addition to nuclear reactors, accelerators played an important role in neutron sources. The energy of accelerated proton or deuteron beams ranged from around 100 keV to about 1 GeV depending on the application demand. Low energy accelerators, like DC high voltage accelerator, cyclotron and RFQ, have been used for neutron radiography, boron neutron capture therapy, neutron activation analysis, etc [1].

The neutron sources based on RFQ or RFQ+DTL have been developed in LLNL[2], South Africa[3] and Indiana[4]. In this paper the design of a deuteron RFQ for neutron generation is described.

BASIC DESIGN CONSIDERATIONS

The main design objectives are to get the higher neutron yield with lower RF power. The fast neutron yield depends on the particle species, target element, particle energy and the average beam current. The reaction Be(d, n) was chosen because the Be target is easier to be handled than Li and the beam energy could be lower with deuteron than proton for the same neutron yield (Fig. 1).

The designed parameters of RFQ accelerator largely depend on the available RF output power of transmitter. We decided not to use klystron due to its big dimension and higher cost. The Thales TH781 was chosen as the final RF output tube, which can deliver 400 kW peak power with more than 10% duty factor at around 200 MHz. Considering the available RF power the deuteron energy at exit of RFQ was set to 2.0 MeV, and the peak current of deuteron beam was designed as 50 mA. So the peak beam power is 100 kW and the peak power consumed in RFQ cavity should be limited below 260 – 280 kW. The frequency of RFQ was chosen as 201.5 MHz. From Fig. 1 the expected 4π fast neutron yield is 4×10^{12} n/s.

At the frequency around 200 MHz, both four-vane and four-rod type structure can be used for RFQ cavity. The four-rod structure was chosen due to its smaller diameter and lower machining precision.

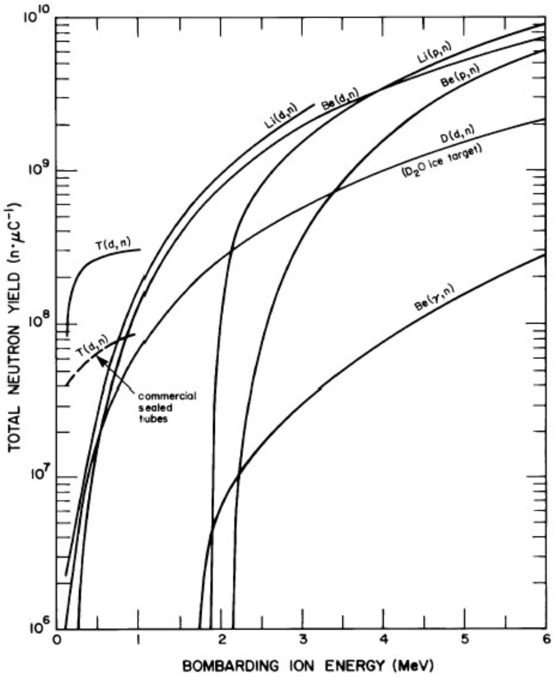

Figure 1: Neutron yields for low energy particle beam reactions[5].

The whole accelerator consists of ion source, LEBT, RFQ cavity and HEBT (Fig. 2), which will be described in the following sections.

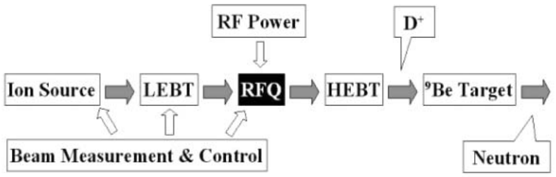

Figure 2: Scheme of the accelerator subsystem.

RFQ CAVITY DESIGN

The RFQ beam dynamics design has been performed with PARMTEQM using the LANL Four Section Procedure[6], but the beam loss is more than the expectation. In order to improve the beam transmission efficiency, two optimization concepts were combined in the new design: (1) the variation of the focusing parameter was adjusted along the RFQ to keep a certain ratio between the focusing force and the space-charge force; (2) main beam dynamics parameters' variation

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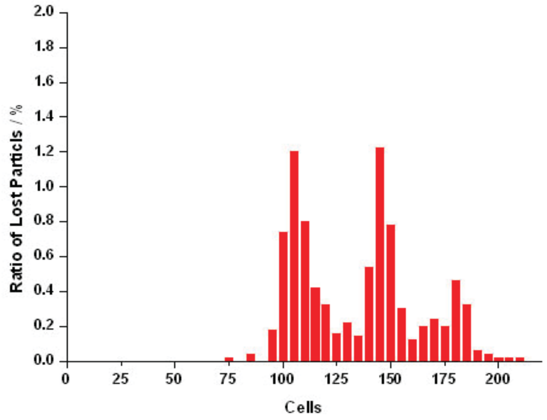
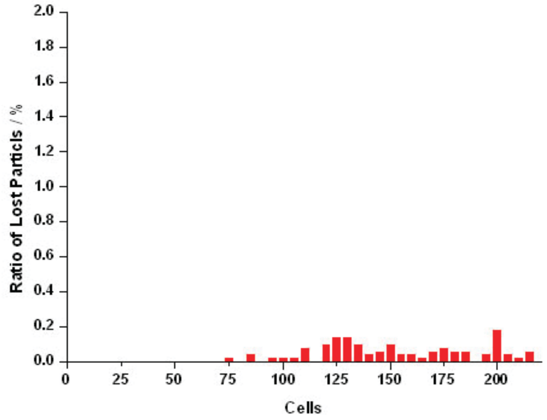
were adequately smoothed, especially at the critical point between the sections of gentle buncher and accelerator. Those optimization not only reduced the beam loss greatly (Fig. 3) but also shortened the structure length. After the optimization, the transmission rose from 91.0% to 98.5%, and the electrode length reduced from 2.91m to 2.71m[7].



(a) Particle lost when the four section procedure was used



(b) Particle lost after the optimization

Figure 3: Transmission improvement by optimization.

The 4-rod RFQ structure with mini-vanes was designed with Microwave Studio (MWS). To get desired frequency, higher electrode voltage and less power loss, higher and thicker stems were adopted. The frequency and shunt impedance are sensitive to the distance between stems, so it should be optimized, too. Every stem is designed with a suitable balancing slope namely a shortcut to decrease the dipole effect. Most sharp angles inside every stem are chamfered to avoid sparking and decrease power consumption. Fig. 4 shows the designed 4-rod RFQ structure.

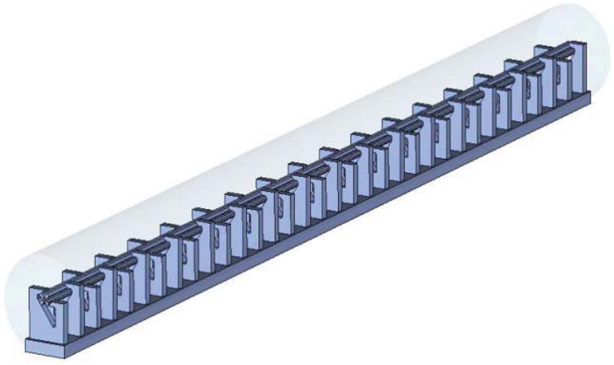


Figure 4: Four-rod RFQ structure designed with MWS.

RF TRANSMITTER

The scheme of RF transmitter is shown in Fig. 5. The 201.5 MHz RF signal is modulated by a PIN modulator, then input to a broad band solid state amplifier, which can give 1 kW RF output. The front stage power amplifier uses a FU-113 tube, which can deliver 20 kW peak RF power. The final power amplifier uses TH-781 tetrode, and its peak RF output power can reach 400 kW. Both front and final power amplifiers are modulated by a pulsed modulator. The PIN modulator and pulsed modulator are controlled by a timer, which generates 0.3 – 1 ms tunable square wave pulse signal with the frequency of 100 – 160 Hz. The 400 kW circulator has an insert loss less than 0.5 dB.

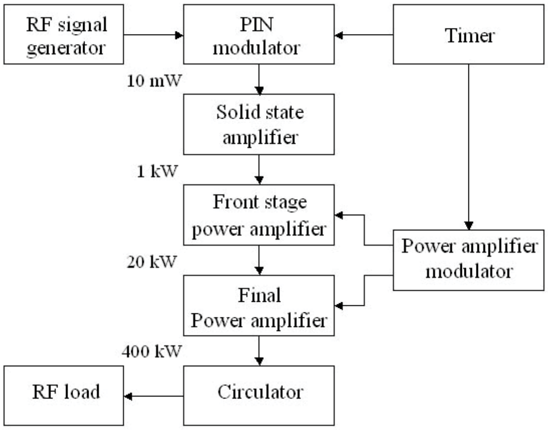


Figure 5: Scheme of the RF transmitter.

ION SOURCE AND LEBT

The deuteron ions are generated by a 2.45 GHz ECR ion source, but the axial magnetic field in the source is a bit higher than the ECR value. A prototype of the ion source with NdFeB permanent magnet rings has been developed. The outer diameter of the source body is 100 mm, and the length is 100 mm, too. The diameter of the discharge chamber is 50 mm, and the total weight is less than 5 kg (Fig. 6). The ion source can be run in either DC or pulsed mode. With pulsed mode more than 100 mA peak current of proton beam can be extracted, the proton ratio is about 80%, and the normalized rms emittance is less than 0.2 π mm.mrad.

A test bench is being set up to investigate the magnetic solenoid performance, space charge compensation and the entrance match of RFQ. A high current ion beam emittance measurement unit has been constructed, too.

Figure: 6 ECR ion source on the test bench.

CONCLUSIONS

A 201.5 MHz 2 MeV deuteron RFQ accelerator has been designed to fit the 400 kW peak RF power. Its transmission was greatly improved by optimization, and its 4-rod mini-vane RF structure was carefully designed. The studies on ion source, LEBT and RF transmitter are in progress. The whole accelerator is expected to give high current deuteron beam for neutron generation in the near future.

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