UPGRADE OF 1 MEV HEAVY ION ISR RFQ ACCELERATOR*

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Abstract

The upgrade of 1 MeV ISR RFQ accelerator has been launched for exploring the possibilities of a few mA heavy ion beam acceleration and its applications on the material science, biological irradiation and RFQ-AMS carbon chronology. A new ECR ion source with extracting voltage of 22kV, and the LEBT matching section have been redesigned and tested to increase the injection beam current and to realize the beam matching. The experimental tests for the different operating parameters have been compared to the simulations by self developed code RFQDYN. The preliminary results will be presented in this paper.

INTRODUCTION

1MeV 26MHz heavy ion ISR RFQ was completed in 1998. It has been operated for eight years with high duty factor of 16% and repetition frequency 166Hz [1]. It needs only 25kW RF peak power to reach the designed inter-vane voltage of 70kV. It has been used to accelerate O^+ , O^- and N^+ to about 65keV/u with energy spread ~3.5%. The accelerated maximum O^- macro-pulse beam current is 660μA with a beam transmission 86%. The cavity is equipped with two turbo-molecular pumps of 450l/m and the vacuum is $2*10^{-4}$ Pa. To enhance the beam transmission and the accelerated beam current, the upgrade of 1MeV ISR RFQ was proposed and launched last year. The two pumps were replaced by two 600 l/m pumps and the vacuum has been improved to $2*10^{-5}$ Pa. The ion source and LEBT are also going to be replaced with new one to enhance the output beam current.

ECR ION SOURCE AND LEBT

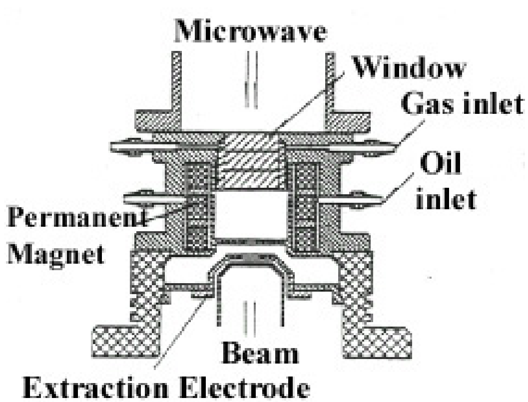

Figure 1: An ECR ion source.

An ECR ion source (figure 1) was tested for O^+ beam extraction on a LEBT test bench, which was originally developed for the deuteron RFQ[2]. The ECR source operates at 2.45GHz and has a single extraction electrode. An O^+ beam of 2.7mA in average can be obtained at an extraction voltage of 22kV with a duty cycle 1ms/6ms. The microwave power delivered to discharging chamber is only 150 W. A dedicated ECR ion source and LEBT base on above experiments were designed (figure 2) and are under construction. The total length from the extraction point to the RFQ entrance is about 738mm. For the safety consideration, the oil circulation system, gas inlet and microwave amplifier are all installed on the ground level.

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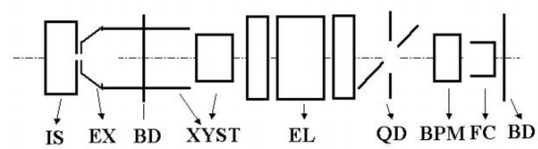

Figure 2: ECR ion source and LEBT (IS: ion source; EX: Extraction; BD:Beam diaphragm; XYST: X and Y steer; EL: Einzel lens; QD: Quadruple diaphragm; BPM: Beam position monitor; FC: Faraday cup).

RFQDYN AND ITS APPLICATIONS

Because of the uncertainty of new ECR ion source emittance for the extracted O^+ beam, the beam transmission efficiencies at different input phase elliptical twiss parameters of alpha and beta have been simulated by RFQDYN code [3], which has been developed for several years based on the very beginning source code of PARMTEQ. Figure 3 and 4 show the accelerated O^+ beam transmission efficiency has no large variation with different input emittance as well as the twiss parameters of alpha and beta, which means the 1MeV ISR RFQ could accept quite different input phase shape of the beam.

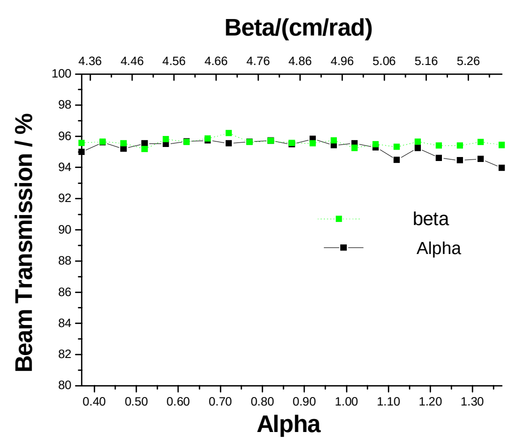

Figure 3: Beam transmission vs different alpha and beta entrance parameters.

But figure 4 indicates the input energy spread (correspondent to 22keV designed input energy) has a large influence on the beam transmission. This requires high voltage stability of extraction power supply should be better than ±0.2%, otherwise beam transmission will decrease quickly.

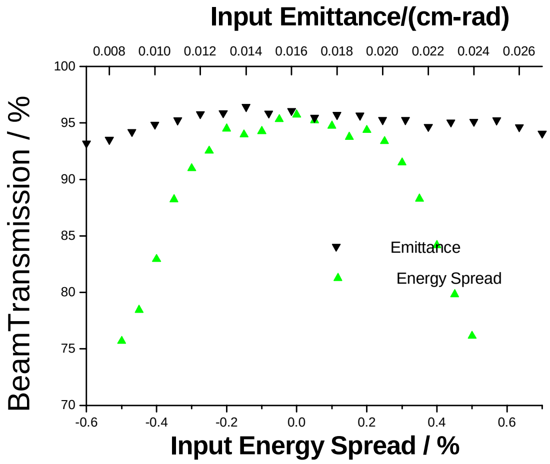

Figure 4: Beam transmission vs different input emittance and energy spread.

The main purpose of developing RFQDYN is to simulate the beam transmission with different operating parameters such as different inter-vane voltages, slight frequency changing, or the acceleration of different ion particles in a RFQ accelerator with fixed configuration. The designed inter-vane voltage of 1MeV ISR RFQ is 70kV. The RFQDYN simulation shows, when inter-vane voltage goes up to 70kV, the beam transmission will gradually reach 91.8% (figure 5), longitudinal and transverse lost particles decrease to 7.3% and 0.9%, respectively. When the inter-vane voltage is greater than 134kV, the transmission will fall down rapidly (in the figure 5), mainly losses of particle are happened in the transverse direction because of over RF focusing (shown in the (figure 6). The experiments have verified the simulated results at lower voltage end. Because of the RF power limitation the simulated results at high voltage end in figure 5 couldn't be proved.

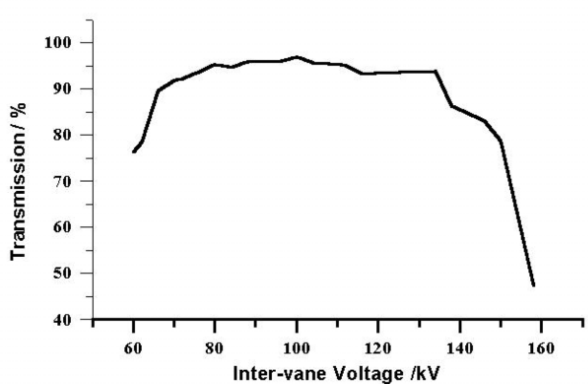

Figure 5: Beam transmission vs inter-vane voltage (O^+, input energy 22.4keV, f=26MHz).

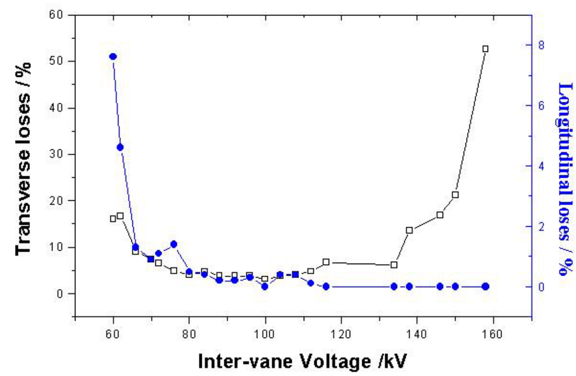

Figure 5: Particle loses vs inter-vane voltage (O^+, input energy 22.4keV, f=26MHz).

The output beam energy spectrum vs different operating inter-vane voltage should also be noticed. Figure 7, 8 and 9 show the RFQDYN simulation results of the output energy spectrum with different inter-vane voltage 60kV, 64kV and 70kV, respectively. For example, one couldn't find the clear peak current in the energy spectrum at 60kV (figure 7), although the corresponding beam transmission reaches about 76%. Experimentally the relative output beam intensity with the energy of the accelerated particles can be measured clearly. This phenomenon has been also verified by the RFQDYN simulation.

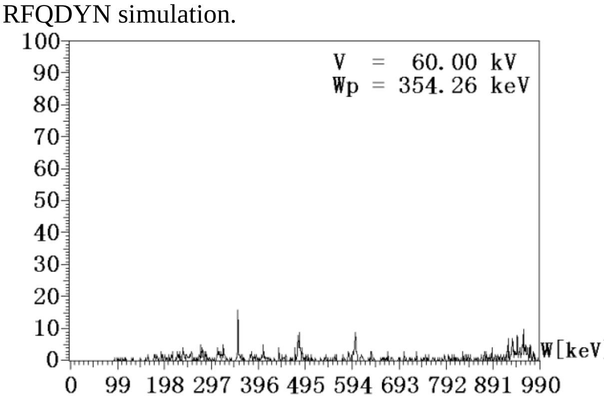

Figure 6: Simulated energy spectrum at 60kV (O^+ beam, input energy 22.4keV, 26MHz).

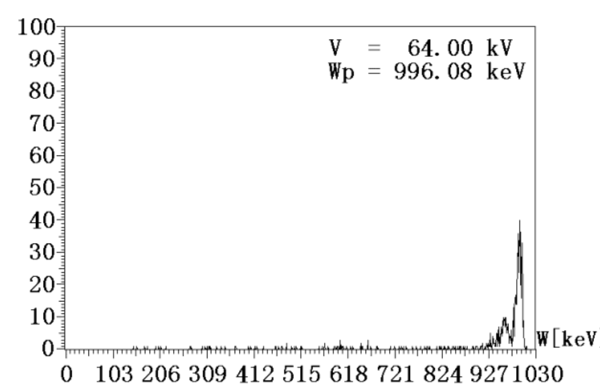

Figure 7: Simulated energy spectrum at 64kV (O^+ beam, input energy 22.4keV, 26MHz).

One could see from figure 9, when the inter-vane voltage reaches 70kV, the output energy spectrum is clean when the particle energy is lower than 954 keV, and many small peaks below that energy in figures 7 and 8 are disappeared.

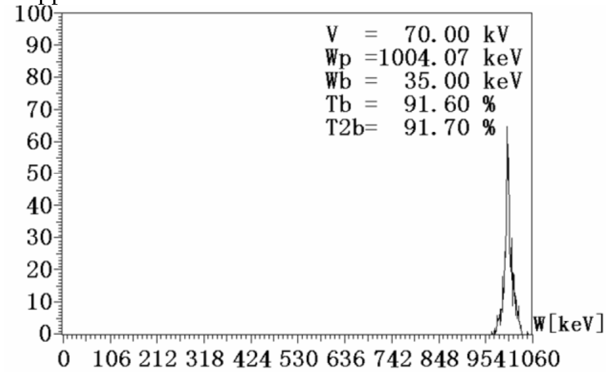

Figure 9:Simulated energy spectrum at 70kV (O^+ beam, input energy 22.4keV, 26MHz).

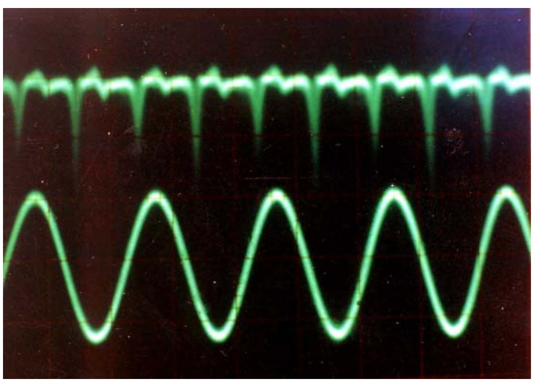

Figure 10: Simultaneous accelerated O^+ and O^- beam in 1MeV ISR RFQ-1000.

For the traditional ion implantation, the accumulation of electric charge is the bottleneck of its applications in material science. So the simultaneous acceleration of positive and negative ions with the same ratio of charge to mass by the RFQ accelerator was proposed in 1996[5]. The experiments of simultaneous acceleration of O^+ and O^- beams in an ISR RFQ were carried out successfully in 2000[6]. Figures 10 shows a picture of measured micro-pulse beam of both O^+ and O^- beam. It is clear that both beams have synchronous phase difference of π.

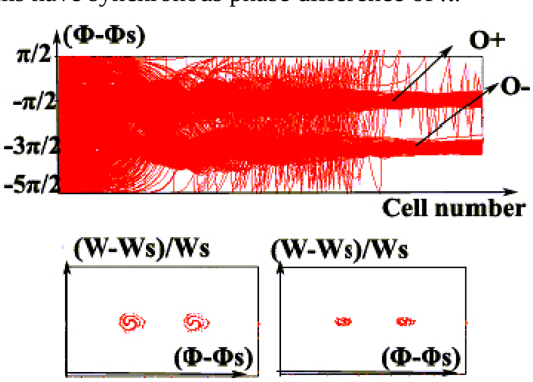

Figure 11: O^+ and O^- simultaneous acceleration.

The simulation of simultaneous acceleration has been also investigated by the modified RFQDYN. The input O^+ and O^- beam were distributed in the phase range of $\pi/2$ to $-5\pi/2$, they are automatically separated, bunched to their own synchronous phase and accelerated to the designed energy 1MeV successfully (figure 11)[7].

CONCLUSION

The upgrade of 1 MeV heavy ion ISR RFQ was launched. An ECR ion source and LEBT were designed on the basis of the test bench experiments and are under construction. The self developed RFQDYN simulation code has been further improved to simulate beam transmission at different operating parameters. The simulation results have been verified by the experiments. The simultaneous simulation for O^+ and O^- beam fits also the experiments performed several years ago. The 1MeV ISR RFQ will be upgraded for high current operation and more applications. The experiments to investigate RFQ-AMS application for the carbon chronology will be carried out with this RFQ soon.

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