RF AND BEAM TESTS OF A 1MEV 26MHZ RFQ AT PEKING UNIVERSITY*

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Abstract

A 1MeV 26MHz RFQ accelerator has been constructed at Peking University. RF power test shows it has the specific shunt impedance 522kΩm, the RFQ inter-vane voltage 70kV at 24kW RF pulse peak power with a duty factor of 1/6. Both positive and negative Oxygen ions and positive Nitrogen ions are accelerated to the designed kinetic energy of 65keV per nucleon with the transmission efficiency more than 83%. The accelerated Oxygen macro-pulse beam current has been beyond 660μA with the RF peak power 25kW with the same duty factor of 1/6. This paper presents and discusses the initial results of RF power and beam tests of the 1MeV 26MHz ISR RFQ accelerator.

1 INTRODUCTION

The history of Integral Split Ring RFQ studies at Peking University was back to 1985[1]. Several years later the first 26MHz ISR RFQ-300 prototype resonator was completed. With the successful RF power conditioning and test of ISR RFQ-300 resonator in 1992, the inter-vane voltage was reached 81.7kV at RF peak power 44.4kW with the duty factor of 1/6. Then the beam outline of ISR RFQ-300 was designed and completed in the beginning of 1994. In the middle of 1994, N^+ beam was accelerated to the designed energy 300keV[2-3]. Then the idea of acceleration simultaneously both positive and negative ions with the same ratio of charge and mass, for example O^+ and O^- ions, in one RFQ accelerator was proposed at Peking University. The test bench for the verification of above idea was completed in 1996. The experiment researches were carried out on ISR RFQ-300 accelerator. With the further improvement of the RFQ beam outline, the transmission efficiency became more than 83%. The output beam current is now near 600μA [4-6]. Meanwhile, a high current 1MeV ISR RFQ accelerator was proposed in 1994 and supported by NNSFC, that is mainly for high energy implantation of N^+, O^+ and O^-. The beam dynamics design, mini-vane electrodes of two dimensional cutting with water cooling channel, the accelerating structure and electrode's supporting system of 1MeV ISR RFQ will be reported in another paper [7] at EPAC2000.

2 RF POWER TEST

1MeV 26MHz ISR RFQ cavity was completed at the end of 1998. Two 450litre/minute turbo-molecular pumps were installed on the bottom base plate of cavity. The vacuum can be better than $5.5*10^{-5}$pa without beam and RF power. Table 1 lists the principal parameters of ISR RFQ-300 and ISR RFQ-1000. The quality factor is 3450 for ISR RFQ-1000, which is much more than 1300 of ISR RFQ-300, it is great profit from the good copper plating and RF connection between cavity bottom wall, Integral Split Ring as supporting arm and RFQ electrodes. Two dimension milling cutter controlled by digital computer fabricated the RFQ electrodes with cooling water channel. The RF system is consisted of 20W (3-30MHz) short wave broadband preamplifier, 1kW driver made by FU100 cooled by air and 30kW CW final amplifier made by FU105Z3 which is cooled by circulating distilled water. It can deliver maximum 50kW in pulse mode with duty factor 1/6. The electric field gradient in the RFQ cavity is stabilized by an AGC feedback system. A distribute capacitance 30pF was added into the RF feeder to compensate the inductance of magnetic coupling loop with cooling water and to realize 75Ω impedance matching between RF amplifier and RFQ cavity. The voltage standing wave ratio is less than 1.1 under the RF power test.

Table 1 Principal parameters of ISR RFQ

	ISR RFQ-300	ISR RFQ-1000
Ion species	N^+ O^+ O^-	O^+ O^- N^+
F(MHz)	26	26
W_{in}(keV)	20	22
W_{out}(keV)	300	1000
Length(cm)	90	260
Diameter(cm)	50	75
V_o(kV)	75	70
Duty factor	1ms/6ms	1ms/6ms

The inter-vane voltage of RFQ was measured by energy spectrum of Roentgen ray. The measuring system consists of a high purity Ge detector cooled by liquid Nitrogen and Ortech computer multi channel system, which was consisted of preamplifier, master amplifier, ISA computer multi channel card and a personal computer. The system was calibrated by two standard γ rays of ^{152}Eu 121.78keV and ^{137}Cs 661.661keV. The maximum electron energy in the measured Roentgen ray spectrum equals the inter-vane voltage of RFQ. The measured inter-vane voltage is 78.6kV at 30kW.

Table 2: The results of RF power test

Power kW	V_o kV	F MHz	T_{water} ℃	ρ kΩm
≈0	≈0	26.200	11.6	
25	70.8	26.196	18.2	511
30	78.6	26.194	19.2	525
35	84.59	26.192	20.7	521

Figure 1 shows us the Roentgen spectrum at RF power

* Supported by NNSFC

30kW with duty factor 1/6.

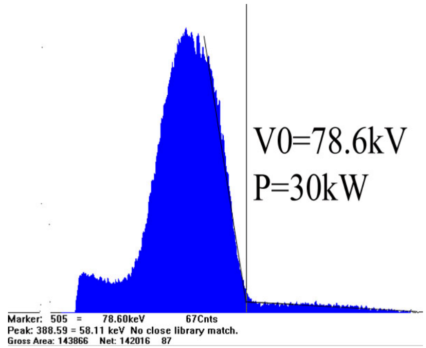

Figure 1: Roentgen spectrum at 30kW RF powers

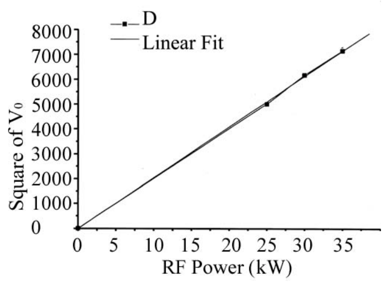

Figure 2: Square of intervane voltage vs RF power

Table 2 lists the results of RF power test with the duty factor 1/6. Here V_o, F, T_{water} and ρ represent inter-vane voltage, resonating frequency, temperature of cooling water and the specific shunt impedance of 1MeV ISR RFQ respectively. Figure 2 is the relation of square of inter-vane voltage via peak RF power. It fits a linear very well with relation coefficient 0.99982. The slope of the line i.e. the shunt impedance is 204.57kΩ. So the specific shunt impedance is about 521kΩm because the length of RFQ electrode is 2.548m. From table 2 we also see the shift of resonating frequency is changed only 8KHz and the temperature of cooling water is increased from 11.6℃ to 20.7℃when RF power is increased from 0 to 35kW. RF power test shows the shunt impedance is almost a constant with the increasing of RF power, and the accelerating structure has enough mechanical strength and RFQ electrodes have been cooled effectively.

3 BEAM TEST

Beam test of 1MeV ISR RFQ was started from April 1999. Figure 3 is the beam outline. There are two permanent magnetic PIG ion sources located at ±45°with the beam axis. One is side extraction PIG ion source with cold cathode; another is end extraction sputtering PIG ion source. They can provide both positive and negative oxygen beams and positive Nitrogen beams, as we need. The extraction beam is focused by its own Einzel lenses (EL) respectively and bent by CM, steered (S) by two parallel plates then focused by another EL to match with the RFQ acceptance. Two Faraday cups (FC) are mounted at the RFQ entrance and exit to measure input I_1 and output I_2 beam current. The energy spectrum of the beam is measured by an analyzing magnet (AM). The third faraday cup is installed at the exit of AM to measure the analyzing beam current I_3. A cut-off coaxial fast target (FT) is mounted at the end of beam line to measure the micro-pulse beam. Vacuum pumps (VP) are 450litre/minute turbo molecular pumps. There are five pumps mounted through the total beam line. The second and the fifth pumps are installed under the El-1 and FC-3 after AM respectively.

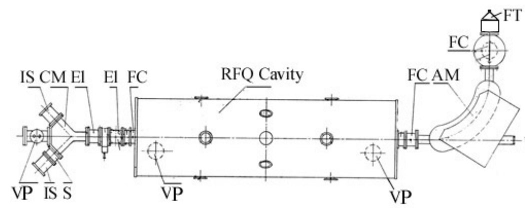

Figure 3: Beam outline of 1MeV ISR RFQ

The discharge voltage of last two ion sources is pulse modulated and synthesized with the RF pulse power. The pulse duration of ion beam and RF power is 1ms and the repetition frequency is 166Hz. Table 3 lists the typical beam test results of O^+, O^- and N^+ ions. Here I_{arc} is discharge current, V_{arc} peak discharge voltage, V_{ex} extraction voltage, P_{rf} pulse peak RF power and η the transmission efficiency.

Table 3: Beam test results of O^+, O^- and N^+

Ion	I_{arc} mA	V_{arc} V	V_{ex} kV	P_{rf} kW	I_1 μA	I_2 μA	η %
O^+	250	1250	22.0	25.0	370	320	86.5
O^+	200	1100	22.0	25.0	240	210	87.5
O^-	300	1350	25.1	25.0	800	660	82.5
O^-	200	1100	25.0	25.0	670	570	85.0
N^+	300	1450	22.3	25.0	350	300	85.7
N^+	200	1100	22.0	25.0	230	200	87.0

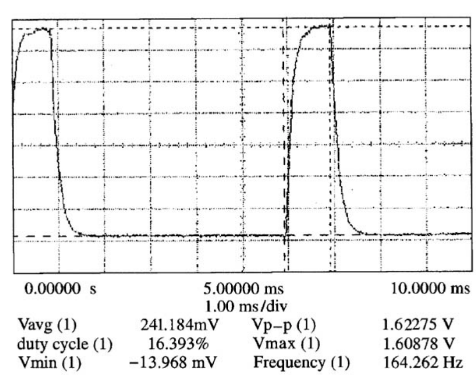

Figure 4: O^+ output beam waveform

We take the O^+ beam test as an example; the pulsed O^+ beam waveform is shown in Figure 4. The macro-pulse beam current is about 320μA, the sample resistor 5kΩ and transmission efficiency 86%. The experimental condition is listed in table 3. It is remarkable here that the transmission efficiency will go up more than 82% when RF power feed into RFQ cavity is more than 24kW. This curve is shown in Figure 5. Figure 6 give us the relation of O^+ output beam current and transmission efficiency with O^+ input energy at entrance of RFQ. It tells us the optimized input energy is about 22keV. Figure 5 and 6 agrees RFQ theory. The O^- micro-pulse beam waveform is shown in figure 7,which is measured by FT (see figure 3). From it we can see clearly the frequency of micro-pulse beam agrees the RF resonating frequency of RFQ cavity. The synchronous phase of O^- ions in figure 7 will be calibrated by the cable length of RF pick up signal, TOF of O^- ions and the response time of FT system in next month.

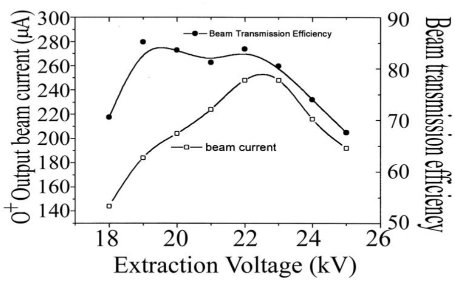

Figure 5: O^+ beam transmission efficiency and beam current with RF power

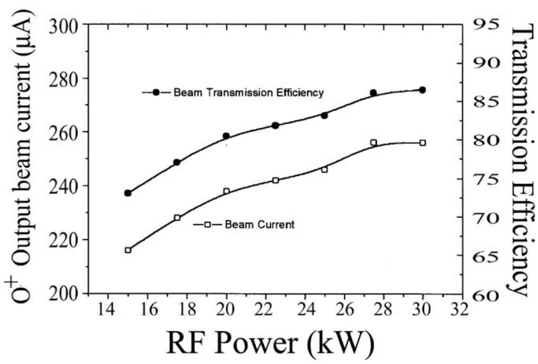

Figure 6: Beam transmission efficiency and beam current with O^+ injection energy of RFQ

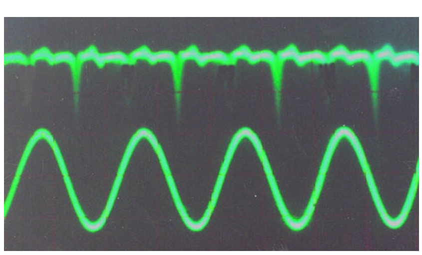

Figure 7: O^- output micro-pulse beam waveform

In order to measure the energy spectrum of accelerated O^+ beam, at first, we measure the relation of magnetic field B (Gauss) via the DC biased current I (A) of analyzing magnet (AM). From the experiment we get:

$$B=324.045*I \qquad (3.1)$$

Then the kinetic energy W (MeV) of O^+ can be calculated from the formula:

$$W = 48.0 \cdot 10^{-8} \cdot (B \cdot r)^2 \cdot (q/A)^2 \cdot A \qquad (3.2)$$

Here r=0.6m, q=1,A=16. W/A is the kinetic energy per nucleon. The kinetic energy spectrum of O^+ output beam at 25kW is shown figure 8. So O^+ ions has been accelerated to 1.025MeV i.e. 64keV per nucleon. The beam energy spread (δW) is about 3.4% from figure 8. Table 4 lists the kinetic energy W of O^+, O^- and N^+ ions.

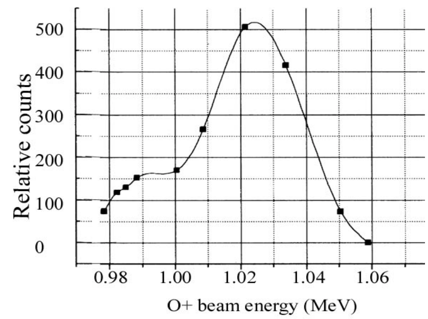

Figure 8: O^+ Energy Spectrum at 25kW

Table 4: The kinetic energy W of O^+, O^- and N^+ ions

Ions	O^+	O^-	N^+
W(MeV)	1.025	1.037	0.930
W/A(keV/a)	64.1	64.8	66.4
δW(%)	3.4	4.0	4.3

4 CONCLUSION

RF power test indicates that 1MeV 26MHz ISR RFQ has 521kΩm of specific shunt impedance and inter-vane voltage is reached 70kV at RF peak power 24kW. O^+, O^- and N^+ beams have been accelerated successfully to 65keV per nucleon with transmission efficiency more than 83%. The output beam current will be improved to be higher with the upgrade of high current ion source. Now the ISR RFQ accelerators at Peking University have been used as N^+ and oxygen ions implanting machines. From now on, application researches of ISR RFQ accelerators and a proton RFQ are proposed.

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