Power test of the separated function RFQ accelerator*

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Abstract The progress of the Separated Function RFQ (SFRFQ) accelerator, which can raise the field gradient of acceleration while maintaining the transverse focusing power sufficient for high current beam, is presented. In order to demonstrate the feasibilities of the novel accelerator, a prototype cavity was designed and constructed. Correspondingly, a code SFRFQCODEV1.0 was developed specially for cavity design and beam dynamics simulation. The prototype cavity will be verified as a post-accelerator for ISR RFQ-1000 (Integral Split Ring RFQ) and accelerate O^+ from 1 MeV to 1.6 MeV. To inject a higher current oxygen beam for the prototype cavity, the beam current of ISR RFQ-1000 was upgraded to 2 mA. The status of high power and beam test preparation for the prototype cavity are presented in this paper.

Key words separated function RFQ, power test, beam dynamic

PACS 29.20.Ej, 29.27.Bd

1 Introduction

As a type of low energy high current linear accelerator RFQs serve well as the first accelerator in a chain of linear accelerators, providing the initial bunching and acceleration of beams. However the accelerating efficiency of RFQ structure is limited, because a large part of RF voltage is used for transverse focusing. Furthermore the efficiency falls off as the fixed voltage is applied to the increasing cell length. The drift tube structure has higher acceleration efficiency, which is why the idea of introducing accelerating gaps into RFQ is also attractive for some applications. For example, SP RFQ[1], RFD[2] as well as chain-like structure[3] which import the accelerating gaps into RFQ, are under investigation in Russia, USA and Japan. As the same reason, the Separated Function RFQ (SFRFQ) was proposed by the RFQ group of IHIP Institute of Heavy Ion Physics) at Peking university[4], based on the experience of ISR-RFQ 1000[5, 6]. Initial results of electro-magnetic calculation and dynamics proved the possibility and higher RF accelerating efficiency of SFRFQ structure[7].

In order to demonstrate the feasibilities of the SFRFQ structure, a prototype cavity was designed and constructed. Correspondingly, a code SFRFQCODEV1.0[8] was developed specially for the cavity design and beam dynamics simulation. The prototype cavity will be verified as a post-accelerator for ISR RFQ-1000 (Integral Split Ring RFQ) and accelerate O^+ beam with ∼mA peak current from 1 MeV to 1.6 MeV. The status of high power and beam test preparation for the prototype cavity are presented in this paper.

2 SFRFQ structure and the first prototype

The electrodes of SFRFQ are shown in Fig 1(a), where diaphragms are mounted onto the quadrupole electrodes with no surface modulation. Then every cell consists of a gap and a small quadrupole lens, the acceleration and focusing will not occur synchronously any more. As the space inside quadruple

Received 6 January 2009
∗ Supported by National Natural Science Foundation of China (10455001)
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is very limited, sparking is a challenge for the SFRFQ structure. In order to decrease the maximum surface electric field and have enough transverse focusing, an asymmetric quadrupole is adopted as Fig. 1(b) shows.

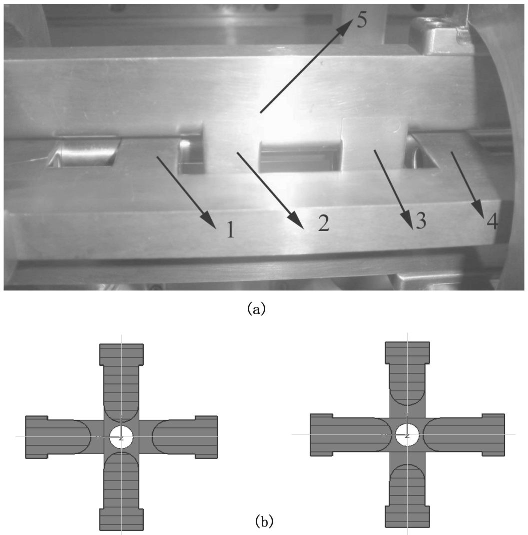

Fig. 1. SFRFQ structure. (a) Photo of the SFRFQ structure (1,2,3 & 4 diaphragms, 5 RFQ electrode); (b) asymmetric quadruple (left for $a_y < a_x$; right for $a_x < a_y$).

As SFRFQ is a hybrid structure of RFQ and DTL accelerator, a special code called SFRFQCODEV1.0 is developed for its beam dynamics design. In order to demonstrate the feasibilities of the accelerator, a prototype cavity with 14 gaps, which accelerates mA oxygen beam from 1 MeV to 1.6 MeV, is designed. The evolution of synchronous phase is plotted in Fig. 2, it shows the four gaps at the entrance are used for beam rebunching, when the 1 MeV O^+ beam is injected from ISR RFQ-1000.

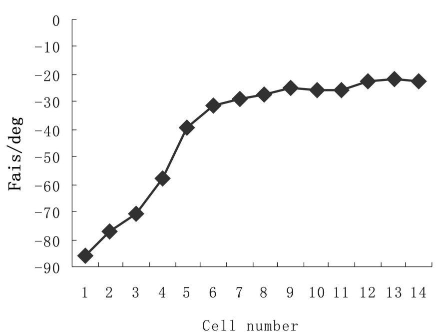

Fig. 2. Synchronous phase versus cell number.

After the beam dynamics simulations and RF structure design, a prototype cavity had been manufactured. Fig. 3(a) and (b) are the photos of the prototype cavity and the tank cover. There is a good RF connection between the cavity bottom wall, the Integral Split Ring and the SFRFQ electrodes. The diaphragms are connected with the electrodes by rivet joint. To have a good cooling, there are water channels inside the supporting ring and electrodes. The principal parameters are listed in Table 1.

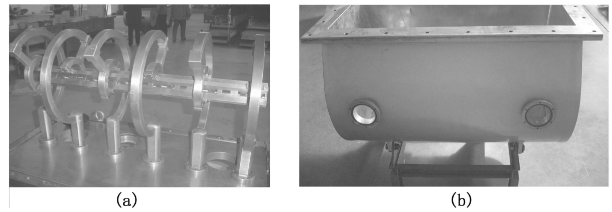

Fig. 3. (a) Prototype cavity; (b) Tank cover.

Table 1. Principal parameters of prototype.

	prototype
ion species	O^+
F/MHz	26.07
W_{in}/keV	1000
W_{out}/keV	1620
cavity length/cm	105.8
diameter/cm	70
V_o/kV	70
duty factor	1 ms/6 ms

3 Low RF test

A capacitance tuner is installed on top of the tank cover. The tuning curve is plotted in Fig. 4. The maximum quality factor is about 2500. The electric field distribution E^2 along the axis is measured by bead pull measurement, Fig. 5 shows the field profile has good agreement with the theoretical curve.

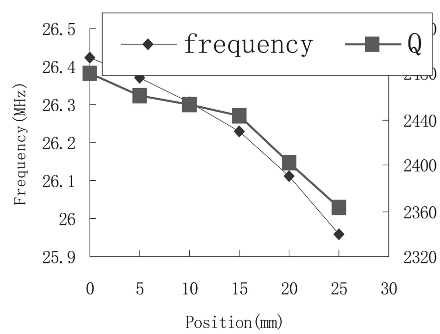

Fig. 4. Tuning curve.

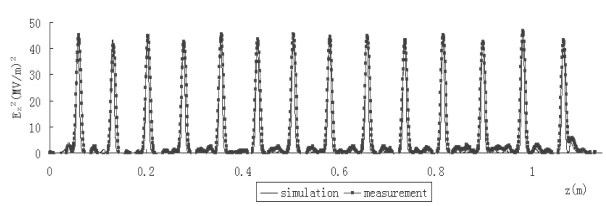

Fig. 5. Axial field $E^2 \sim z$.

4 High power test

Two 450litre/second turbo-molecular pumps were installed on the bottom plate of the prototype cavity. The vacuum can be better than 8.8×10^{-5}pa without beam and RF power. It gets great profit from the good copper plating and RF connection between cavity bottom wall, Integral Split Ring (supporting arm) and RFQ electrodes. Two-dimension milling cutter controlled by digital computer fabricated the RFQ electrodes with cooling water channel. The RF system consists of 20 W (3—30 MHz) short wave broadband preamplifier, 1 kW driver made by FU100 cooled by air and 30 kW CW final amplifier made by FU105Z3 which is cooled by circulating distilled water. It can deliver maximum 40 kW in pulse mode with duty factor 1/6. The electric field gradient in the RFQ cavity is stabilized by an AGC feedback system. The voltage standing wave ratio is less than 1.1 under the RF power test.

The inter-vane voltage of RFQ was measured by bremsstrahlung spectrum of Roentgen ray. The measuring system consists of a high purity Ge detector cooled by liquid Nitrogen and ORTEC computer multi channel system, which consists of preamplifier, master amplifier, PCI computer multi channel card and a personal computer. The system was calibrated with two standard γ rays of ^{241}Am 59.5 keV and ^{137}Cs 661.661 keV. The inflexion in the measured Roentgen ray spectrum equals the inter-vane voltage of RFQ. Fig. 6 shows us the Roentgen spectrum at RF power 28.8 kW with duty factor 1/6. The measured inter-vane voltage is 86.22 kV.

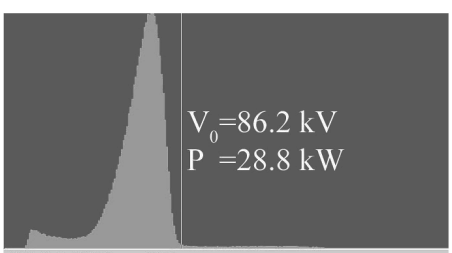

Fig. 6. Roentgen spectrum at 28.8 kW RF powers.

Table 2 lists the results of RF power test with the duty factor 1/6. Here V_o is the inter-vane voltage, $\rho=\frac{v_0^2}{p}\cdot l$ is the specific shunt impedance, where p and l are the RF power and length of the cavity. The relation of square of inter-vane voltage versus pulse RF power is linear. The slope of the line for specific shunt impedance is 256.08 kΩ as Fig. 7 shows, so the specific shunt impedance is about 270.8 kΩm. The accelerating structure has enough mechanical strength and RFQ electrodes have been cooled effectively.

Table 2. The results of RF power test.

power/kW	V_o/kV	ρ/(kΩ·m)
16.2	65.81	276.2
20.7	73.16	265.7
23.4	78.06	269.8
28.8	86.22	266.6
33.3	91.02	257.1

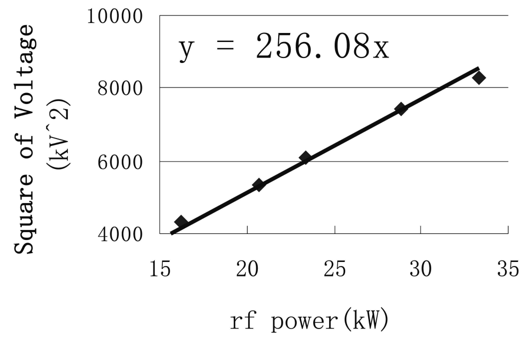

Fig. 7. Square of intervane voltage vs RF power.

5 Preparation for beam test

In order to test the prototype cavity with mA current oxygen beam, ISR RFQ-1000 is upgraded and a new ECR ion source and LEBT are designed and built[9]. The output beam current of ISR RFQ-1000 has reached 2 mA. After the full power test of the prototype cavity, beam test will be going along. Fig. 8 is the beam line. Two Faraday cups (FC) are mounted at the RFQ entrance and exit to measure the input I_1 and output I_2 beam current. The energy spectrum of the beam will be measured by an analyzing magnet (AM). The third and fourth faraday cup are installed at the exits of SFRFQ and AM to measure the beam current I_3 and I_4.

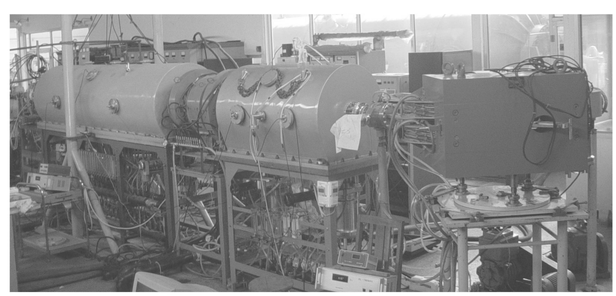

Fig. 8. Beam line.

6 Conclusion

Initial results of dynamics simulations and full RF power test have proved the feasibility and higher

RF efficiency of SFRFQ structure. RF power test of the prototype indicates that the maximum voltage has reached 91 kV, which is about 2.1 Kilpatric electric field. It has about 271 kΩ·m of specific shunt impedance and inter-vane voltage is 70 kV at the RF peak power of 18 kW. The beam test will be carried out later this year. Furthermore, both RFQ and SFRFQ electrodes can be excited by the Split rings, so it is possible that they are coupled and excited inside one cavity. To explore the possibilities, we plan to build an RFQ + SFRFQ combined injector in the near future.

The authors would like to thank Prof. Dr. H. Klein and Prof. Dr. U. Ratzinger for their helpful discussions about SFRFQ.

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