BEAM COMMISSIONING OF SEPARATED FUNCTION RFQ ACCELERATOR

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Abstract
The beam commissioning of Separated Function RFQ (SFRFQ) accelerator, which can gain high accelerating efficiency and enough focusing strength for low energy high current beam, is presented. In order to demonstrate the feasibilities of this novel accelerator, a prototype cavity was designed and constructed. The O^+ beam was accelerated from 1MeV to 1.6MeV by SFRFQ cavity. A triplet was constructed for the transverse beam matching between the 1MeV ISR-RFQ 1000 and SFRFQ. A capacitance frequency tuning system and RF phase shifter were used to keep SFRFQ cavity working at the same frequency of ISR RFQ at the right phase. The whole RFQ accelerator system and the preliminary beam test results are presented in this paper.

INTRODUCTION

The RFQ accelerators are widely used to accelerate low energy intense heavy ion and proton beams nowadays. The RFQ team at Peking University has been engaged in developing RFQ technology by the end of 1980s. Since then a 300keV heavy ion Integrated Split-ring Resonator RFQ (ISR RFQ-300) with the mini-vane electrodes was constructed and put into operation in 1994. Based on these experiences, A 1MeV heavy ion ISR-RFQ (Integral Split Ring RFQ) 1000 was completed and run successfully in 2000[1].

Although RFQ structure has many advantages in accelerating low energy beam, the accelerating efficiency of RFQ structure is rather limited, since a considerable fraction of RF voltage is used for transverse focusing. Further more the efficiency falls off as the fixed voltage will be applied to the increasing cell length. Comparatively, 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 [2], RFD [3] as well as chain-like structure [4] which introduces the accelerating gaps into RFQ, were under investigation in Russia, USA and Japan. For the same reason, the Separated Function RFQ (SFRFQ) was proposed by the RFQ group of IHIP (Institute of Heavy Ion Physics) at Peking university [5], based on the experience of ISR-RFQ 1000. Preliminary results of electro-magnetic and beam dynamics calculation proved the possibly higher RF accelerating efficiency of SFRFQ structure [6].

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In order to demonstrate the feasibilities of the SFRFQ structure, a code SFRFQCODEV1.0[7] was developed specially for cavity design and beam dynamics simulation and a prototype cavity was designed and constructed according to the simulation results. The prototype cavity will be verified as a post-accelerator for ISR-RFQ 1000 and accelerate O^+ beam with ~mA peak current from 1MeV to 1.6MeV. A match section between 1MeV RFQ and SFRFQ is designed for the transverse beam emmitance matching. Meanwhile to upgrade the beam current to mA for ISR RFQ-1000, a new designed ECR ion source for this accelerator has been developed in the last two years [8]. The whole system of accelerators and the beam test results of the system will be presented in the following sections.

SYSTEM OF ACCELERATORS

The RFQ accelerator complex, which is shown in figure 1, consists of ECR ion source, LEBT, 1MeV RFQ accelerator, a triplet matching section, SFRFQ and analyzing magnet.

The old penning ion source was replaced by an ECR ion source, which is made of permanent magnets working at 2.45GHz. The magnet can generate 90~100mT axial magnetic field in discharging chamber. Two electrodes are used for ions extraction. The pure O_2 is used as working gas for ion source.

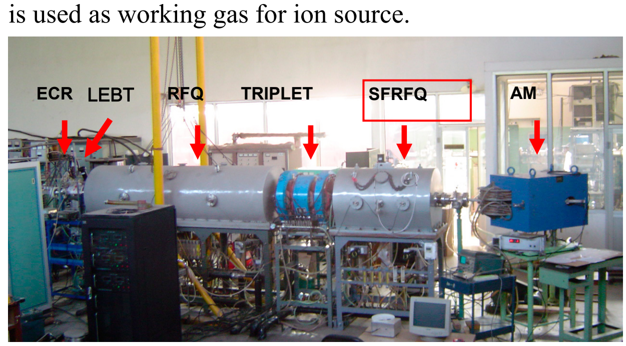

Figure 1: Accelerator system composed by ISR-RFQ 1000 and SFRFQ.

LEBT includes two electric lenses and a faraday cup, which is shown in figure 2. The first lens is composed by two diaphragms and one tube, the diameter of which is 80mm. the second is of three tube type Einzel lens with 120mm diameter. Faraday cup is put behind two lenses near the RFQ entrance. In order to avoid unacceptable high current entering the RFQ, which may damage the RFQ electrode and deteriorates the vacuum, a diaphragm with 15mm diameter is put after faraday cup at the entrance of the RFQ. When ion source works at 1/6 duty factor with 1ms pulse width, the total extracted beam peak current, which is measured on faraday cup, can reach 6-10mA at 22kV extraction voltage. The extracted O^+ ion ratio is about 0.8 and LEBT transmission efficiency is 80%. The normalized RMS emmitance of beam is about 0.15pi•mm•mrad.

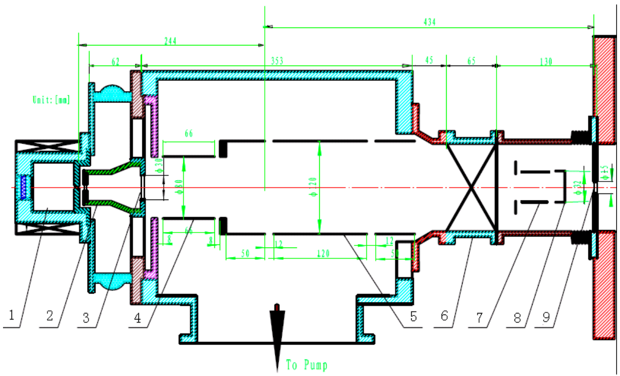

Figure 2: Structure of ion source and LEBT. 1) ion source; 2) extraction electrode; 3) diaphragm; 4) first electric lens; 5) second electric lens; 6) vacuum valve; 7) suppression electrode; 8 faraday cup 9) diaphragm.

ISR-RFQ 1000 is a 4-rod RFQ with mini-vane electrodes. It is designed to accelerate ion O^+ to 1MeV with a 5mA beam current as the upper limit.

The output beam from the RFQ accelerator defocuses rapidly in both x and y directions, it can't be injected to SFRFQ directly. So a triplet is designed to make the beam match in transverse phase space. Because the longitudinal phase width of beam is increased when beam goes through the triplet, the triplet beam line should be design as shorter as possible. The triplet beam line is designed with trace-3d program. The simulation result with an ideal input beam emittance is shown in the figure3. A faraday cup is set after the triplet near the entrance of SFRFQ.

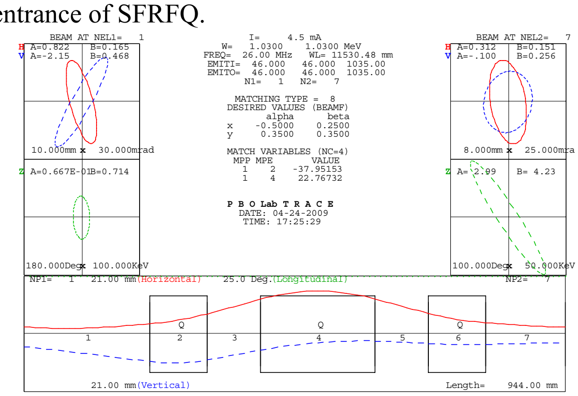

Figure 3: The simulation result of triplet beam line.

Beam dynamics of SFRFQ is designed with SFRFQCODEV1.0. The beam dynamics simulation result shows the transmission efficiency of beam can reach 94%. Figure4 shows the simulation result.

The machine error of SFRFQ is also analysed with SFRFQCODEV1.0 [9]. The results show that the transmission efficiency is sensitive to the asymmetry of the aperture. The higher aperture asymmetry, results in lower transmission efficiency. When the asymmetry of the aperture exceeds 0.2mm, the transmission efficiency is below 90%. Relative to asymmetry of aperture, the longitudinal position error of diaphragm has less effect on the transmission efficiency and the beam output energy. When longitudinal position error is below 1mm, the beam transmission efficiency is acceptable. The SFRFQ accelerator works with high duty factor, the cooling structure of it is designed according to error analysis result. The maximum thermal deformation of SFRFQ structure is less than 60µm with 1/6 duty factor, 22kw input peak power. Figure 5 is the sketch of the cooling structure.

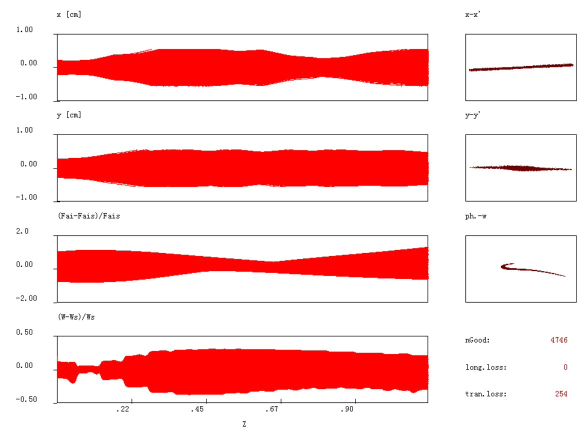

Figure 4: Simulation result of beam transmission in SFRFQ.

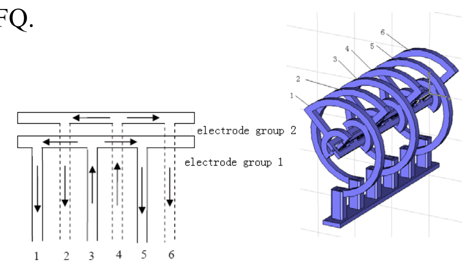

Figure 5: Cooling structure of SFRFQ.

RF SYSTEM

Two RF amplifiers can deliver a maximum power of 40 KW each for two accelerators in pulse mode operation with a duty factor of 1/6. The same signal generator is used for both power suppliers working in pulse mode. The ion source shares the same trigger pulse with the power amplifiers. The figure7 shows the RF system sketch. A voltage controlled phase shifter is used in RF system for the SFRFQ accelerator to adjust the RF phase of the synchronous particle at middle of the first gap to a proper value. A capacitance tuner is installed in SFRFQ cavity; it can tune cavity's frequency from 26.42MHz to 25.95MHz with a step motor at open loop. During the working period, the resonating frequency of both cavities would drift very slowly. So the tuner of SFRFQ is controlled manually to keep the working frequency of SFRFQ be the same with ISR-RFQ 1000.

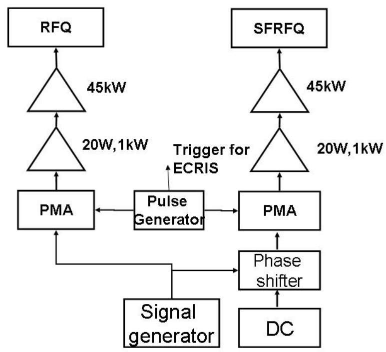

Figure 6: RF system.

BEAM TEST

After the triplet and SFRFQ cavity are installed on the beam line, the beam test experiment is carried out. The first beam of 162μA is measured at exit of SFRFQ by faraday cup with 1/6 duty factor at 166Hz repetition frequency. After first beam is measured, many parameters are changed to optimize the output beam quality of SFRFQ. The voltages of extraction and electric lenses are changed to improve the input beam quality of ISR-RFQ 1000. The exciting currents of triplet are changed to find the best input beam parameter of SFRFQ. The voltage of phase shifter is very important for beam test, so the voltage is scanned in a wide range to find an optimized voltage. So far, the best beam test result is 250μA at exit of SFRFQ. The experiment condition is listed in table1.

The beam energy analysis is done with analysis magnet and the result is recorded with x-y recorder. It matches with simulation result with SFRFQCODEV1.0, the experiment result is shown in the figure7.

Table 1: The Experiment Condition

Experiment condition	First result	Best result
Duty factor	1/6	1/16
Repetition frequency	166Hz	166Hz
Vacuum of discharge chamber	2.0×10^{-4}Pa	2.4×10^{-4}Pa
Extraction voltage	22.5kV	25kV
Voltage of lens 1	16.7kV	16.7kV
Voltage of lens 2	19.5kV	19.5kV
Input power of RFQ	28kw	31kw
Vacuum of RFQ	2.7×10^{-4}Pa	2.2×10^{-4}Pa
Input power of SFRFQ	20kw	20kw
Vacuum of SFRFQ	5.0×10^{-4}Pa	4.9×10^{-4}
Current of triplet magnet 1	65.0A	56.6A
Current of triplet magnet 2	47.5A	41.2A
Current of triplet magnet 3	65.0A	30.0A
Voltage of phase shifter	4.9V	3.4V
Working frequency	26.075MHz	26.074MHz

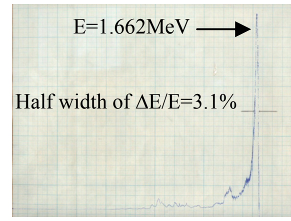

Figure 7: beam energy spectrum of experiment.

The beam current measured at faraday cup near the entrance of SFRFQ is about 3mA, while the inputted O^+ beam for the 1 MeV RFQ is ~4 mA. A large part of beam is lost in SFRFQ cavity. The main possible reason is: the beam spot at the entrance of SFRFQ cavity is 11mm in x direction and 17mm in y direction, so it is much bigger than ideal beam spot and exceeds the acceptance of SFRFQ cavity. Big beam spot might come from beam emittance considerable increment in the 1 MeV RFQ. The method to reduce the input beam emittance will be studied in the near future.

CONCLUSION

Beam test shows that the SFRFQ have high acceleration efficiency. The extraction voltage of ion source, voltage of electric lenses, the triplet current and the voltage of phase shifter effect the output beam of SFRFQ. Although the beam transmission in SFRFQ is low, the energy spectrum of SFRFQ is match well with simulation result. In experiment we find the main reason of the beam loss in SFRFQ and will improve it in the near future.

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