Acceleration Test of Heavy-Ion with TIT RFQ Linac

Noriyosu HAYASHIZAKI, Toshiyuki HATTORI, Kimikazu SASA, Takashi ITO,
Katushi ISOKAWA and Satoshi MAJIMA
Research Laboratory for Nuclear Reactors, Tokyo Institute of Technology
2-12-1, O-okayama, Meguro-ku, Tokyo, 152 JAPAN

Abstract

A heavy-ion acceleration system with the TIT-RFQ has been developed. The TIT-RFQ was designed to accelerate particles with a charge to mass ratio ε ≥ 1/16, as it was, the kind of particles was limited because of the insufficient withstanding voltage of the beam injection equipment. In order to solve this problem, the development of the new system was planed, and the work has been carried out since last year. By using this system, the first acceleration of N^+ beam was observed in January this year; however, the beam intensity was insufficient. Some problems were pointed out, and the synchronous circuit of a RF pulse was constructed up to now. By using this circuit, the increase of the beam intensity was observed in the second acceleration test in this summer.

1 Introduction

The TIT-RFQ has been operated for the basic researches on heavy-ion inertial fusion and ion-pumped laser[1-2]. To accelerate heavy-ions with the TIT-RFQ is very important to perform more effectively the experiments, and moreover, it is interesting to estimate the performance of the accelerator. The TIT-RFQ was designed to accelerate particles with a charge to mass ratio ε ≥ 1/16 from 5 keV/u up to 219 keV/u. As it was, the acceleration particles were limited to the ones with ε ≥ 1/4 because of the insufficient withstanding voltage of the beam injection equipment.

In order to solve this problem, the development of a new heavy-ion acceleration system was planed, and the work has been carried out since last year. By using this system, the first acceleration of N^+ beam was observed in January this year; however, the beam intensity was insufficient[3-4]. To obtain the intense beam, some problems were pointed out, and the synchronous circuit of a RF pulse was constructed up to now. By using this circuit, the beam intensity of six times of the asynchronous result was obtained in the second test in this summer. The results of the acceleration test and an outline of the system are presented.

2 Outline of new heavy-ion acceleration system

The previous system has been operated with He^+ beam, and its intensity was 2.5 mA at the ion source and 1.6 mA after the acceleration. In the new system, N^+ and O^+ with ε ≈ 1/16 were selected as the principal acceleration particles. The importance in a design was to transport and accelerate stably both of particles. The first and second acceleration tests, however, were performed for N^+ and He^+ because of the insufficient aging of the accelerator. The new system consists of the TIT-RFQ, a hexapole cusp-field type ion source, acceleration columns, a solenoid lens, an einzel lens, magnetic quadrupole lenses and an analyzing magnet. The arrangement of the system components shown in Fig 1, and they are described the following.

TIT-RFQ

The TIT-RFQ constructed on 1993 is 4-vane type RFQ linac[5-6]. The principal parameters are shown in Table 1. The beam transmission efficiency observed in the previous system was 90 % of the expected value.

Table 1 Principal parameters of the TIT-RFQ

Charge to mass ratio	≥1/16
Operating frequency [MHz]	80.9
Input beam energy [keV/u]	5.0
Output beam energy [keV/u]	219.0
Normalized acceptance [πmm·mrad]	0.5
Duty factor[%]	10.0
Expected beam transmission [%]	
10 mA input	91.8
0 mA input	68.4

Ion Source

In the previous system, a 2.45 GHz ECR ion source was operated; however, its maximum extraction voltage was 25 kV. In the new system, the hexapole cusp-field type ion source was constructed and set on the high voltage terminal. Ions are generated with the microwave of 2.45 GHz of a pulse mode. The input beam energies of N^+ and O^+ are 70 keV and 80 keV, respectively. It is obtained by using the extraction voltage from the ion source and the acceleration columns with the withstanding voltage of 40 kV and 60 kV, respectively.

The qualities of the beam extracted from the ion source were measured for He^+ and N^+. The measurement system consisted of the ion source, the einzel lens and a small analyzing magnet. The extraction voltage and the duty of the beam pulse were 20 kV and 17 %, respectively. In the beam spectrum measurement, the generated rates of N^+ and N_2^+ from N_2 gas were observed 18 % and 91 %, respectively. The maximum average intensity of N^+ was 14 μA, and by considering the pulse duty, this result corresponds to the peak intensity of about 80 μA. The generated rate of He^+ was greater than 99 %, and its intensity was 80 μA.

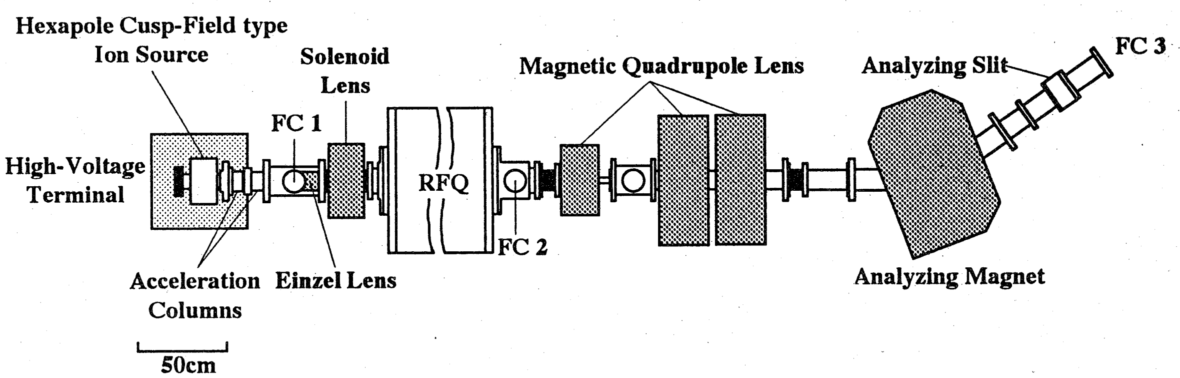

Fig. 1 Schematic drawing of the new heavy-ion asseleration system

Beam Focusing

A focusing force of an electromagnetic lens must increase in proportion to beam energy. Therefore a solenoid lens without the problem of electric discharge was selected as the substitute for the einzel lens. The maximum magnetic field of this lens is 6.8 kG, as it is, it is 3.8 kG at present because of the limit of a power supply. The einzel lens was remained to assist the solenoid lens. The triplet magnetic quadrupole lenses of an analyzing system were unchanged.

3 Improvement of RF synchronization

The first acceleration of N^+ beam was observed by using the new system in January this year; however, its intensity was nA order. The causes of this problem were the asynchronizaton of the RF pulse and the beam pulse, the insufficient beam extraction from the ion souse and the insufficient beam focusing. The cycle of RF pulse of the TIT-RFQ is variable in 30 ~ 300 ms. The one of beam pulse is invariable on 20 ms. In the first test, the beam was accelerated with the RF cycle of 33 ms; the synchronous cycle of 100 ms. The observed beam had a beat because the synchronization was insufficient, and the beam transmission efficiency was 0.2 ~ 0.3 %. In order to this problem, the synchronous circuit of the RF and the beam was constructed. The signal picked up from the ion source is modified by the circuit of Fig 2, then, it is sent in the accelerator controller. By using this circuit, it was possible to accelerate the beam with synchronous pulse of 20 ms cycle. The improvement of the ion source and the focusing lens is performed in the near future.

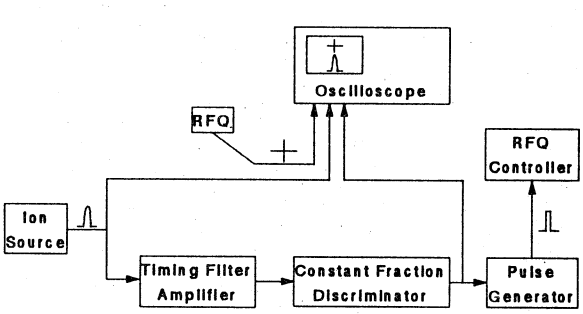

Fig. 2 Schematic drawing of the signal modifier

4 Acceleration Test

The acceleration test with the synchronous circuit was performed for N^+ and He^+. The measured beam property were the beam spectrum and the relationship between the beam intensity and the RF power fed to the accelerator. The width of the RF pulse was 150 μA for N^+ and 300 μA for He^+ because of the duty. The maximum RF power was 60 kW in this test; however, the sufficient power to accelerate N^+ beam is 80 kW. The total intensity of N^+ and N_2^+ at FC 1 was 27.5 μA, and the one of He^+ was 52 μA. The accelerated beam was measured at FC 3.

The energy spectrum of N^+ beam accelerated with the synchronous circuit is shown in Fig. 3. Its peak energy was 3.07 MeV, and the energy distribution was ± 0.07 MeV. In the asyncronous acceleration, the sawtooth spectrum was observed because of the beat of a pulse.

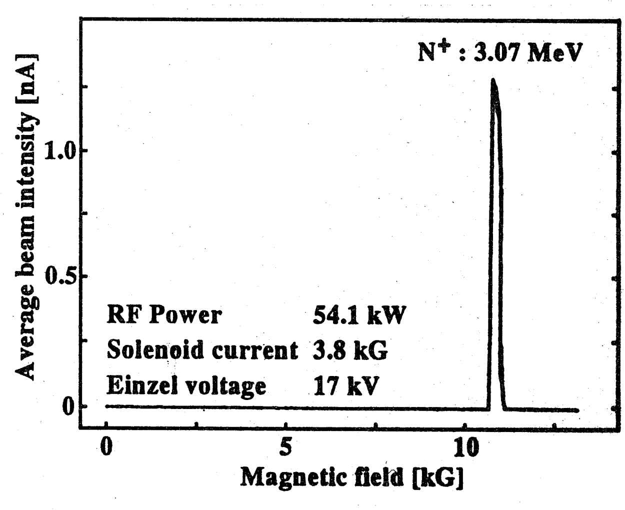

Fig. 3 Energy spectrum of the accelerated N^+ beam

The relationship between the beam intensity and the RF power for N^+ is shown in Fig. 4. The maximum averaged intensity in synchronous result was 15 nA, and it was six times of the one in asynchronous result. The RF power of 45 ~ 60 kW for N^+ corresponds to 3.7 ~ 4.8 kW for He^+. The results for He^+ are shown in Fig. 5. Consequently, the starting conditions of the acceleration of both are similar. The intensity of N^+ will be increased and saturated by increase of the RF power. The beam transmission efficiency is estimated after the emittance measurement presently.

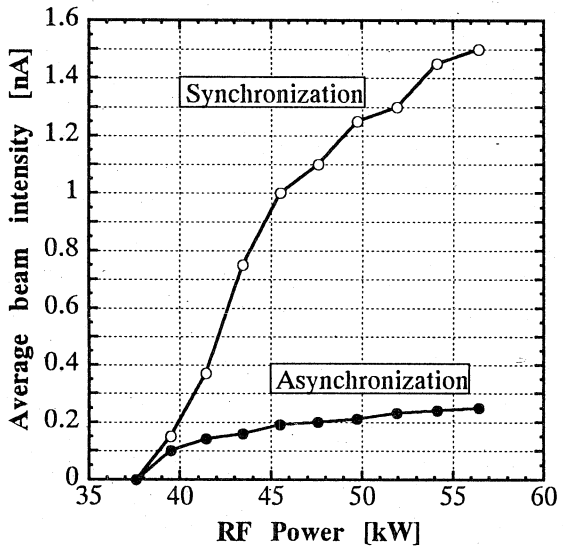

Fig. 4 Relationship between the N^+ beam intensity and the RF power. The focusing conditions of the solenoid and einzel lens were 3.8 kG and 17 kV, respectively.

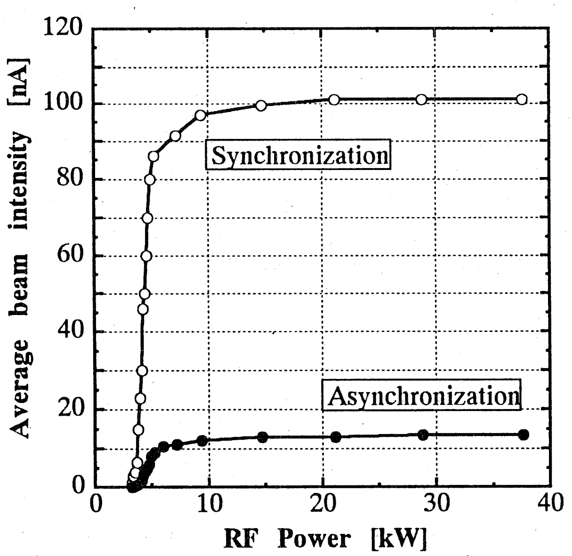

Fig. 5 Relationship between the He^+ beam intensity and the RF power. The focusing conditions of the solenoid and einzel lens were 3.8 kG and 0 kV, respectively.

5 Conclusion

The heavy-ion acceleration system with TIT-RFQ has been developed. By using this system, the acceleration of N^+ beam was possible. In the second test with the synchronous circuit, the maximum averaged intensity of 15 nA for N^+ beam was obtained, and it was six times of the one in asynchronous result. The beam transmission efficiency is estimated after the emittance measurement presently.

The new system cannot be applied for the experiments because of insufficient intensity. In order to increase the beam intensity, we intend to power up the solenoid lens and the RF power in this year. The improvement of the ion source is planed after next year.

References

[1] K.Sasa et al., Fine-focusing system of intense beams for application of ion-induced plasma, Nuclear Instruments and Methods in Physics Research, B113(1996)67-70

[2] K.Sasa et.al., Measurements of plasmas induced by $^4He^+$ beams from r.f.quadrupole linac, Fusion Engineering and Design, 32-33(1996)547-550

[3] N.Hayashizaki et al., Heavy-ion acceleration experiments on RFQ Linac, Proceedings of the 16th RCNP Osaka intenational symposium, to be published.

[4] N.Hayashizaki et al., Acceleration test of heavy-ion in RFQ Linac for HIF basic experiments, Proceedings of IAEA Technical committee meeting, to be published.

[5] M.Okamura et al., Design and construction of heavy-on RFQ linac with effective acceleration structure, Nuclear Instruments and Methods in Physics Research, B89(1994)38-41

[6] M.Okamura et al., Acceleration test of heavy-ion RFQ linac at TIT, Nuclear Instruments and Methods in Physics Research, B99(1995)694-696