Acceleration Tests of the INS 25.5-MHz Split Coaxial RFQ

S. Arai, A. Imanishi, T. Morimoto, S. Shibuya*, E. Tojyo, and N. Tokuda
Institute for Nuclear Study, University of Tokyo
Tanashi, Tokyo 188, Japan

Abstract

The INS 25.5-MHz split coaxial RFQ, a linac that accelerates ions with a charge-to-mass ratio greater than 1/30 from 1 to 45.4 keV/u, is now undergoing acceleration tests with a beam of molecular nitrogen (N_2^+) ions. Results so far obtained show that the RFQ operates in accordance with the design. Presented are preliminary results on the beam performance: emittances of the in- and output beams, output energy and its spread, and beam transmission.

I. INTRODUCTION

At the Institute for Nuclear Study (INS), we are conducting acceleration tests of a 25.5-MHz split coaxial RFQ (Radio Frequency Quadrupole) by using molecular nitrogen (N_2^+) ions. This linac accelerates ions with a charge-to-mass ratio greater than 1/30 from 1 to 45.4 keV/u. The whole cavity, 2.1 m in length and 0.90 m in inner diameter, consists of three module-cavities and has modulated vanes. The cavity underwent successfully low-power tests (frequency tuning, Q-value measurement, measurements of field strengths near the vane tips) and rf conditioning [1, 2, 3]. On January 22, 1991, the first beam acceleration was performed: N_2^+ ions were accelerated up to the design energy.

This paper describes preliminary results of acceleration tests so far conducted. Since the present low-energy beam transport line has no device for ion separation, the input beam contains ions other than N_2^+ ones. Though this prevent us from clear discussion on the beam performance, preliminary results are consistent with PARMTEQ predictions.

II. ACCELERATION TEST STAND

The setup of the acceleration test stand is shown in Fig. 1. Nitrogen ions are provided by a 2.86-GHz ECR (Electron Cyclotron Resonance) ion source. The source is a compact one, equipped with permanent magnets: six bar magnets for a sextupole field and two ring ones for a mirror field in the axial direction. Ions are extracted from the source at a potential of 28 kV.

In the low-energy beam transport line, four einzel lenses focus the beam and match its emittance with the RFQ acceptance. The voltages applied to the einzel lenses were optimized by using a computer code TRACEP, a ray tracer [4]. TRACEP simulates the particle motion in an einzel lens, whose electric field is computed by SUPERFISH. In the present system, we cannot discriminate the aimed N_2^+ ions from the contamination of other ions: N^+, N^{++}, and H_2O^+. This problem will be soon solved by installing a bending magnet between einzel lenses 2 and 3.

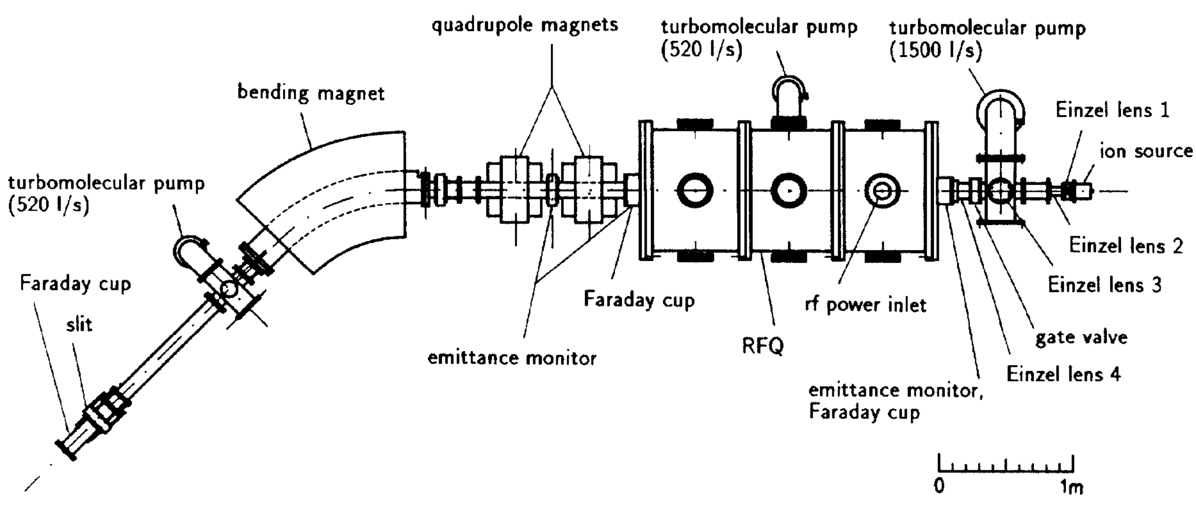

Figure 1. Setup of the acceleration test stand.

*The Graduate University for Advanced Studies, KEK, Tsukuba, Ibaraki 305, Japan

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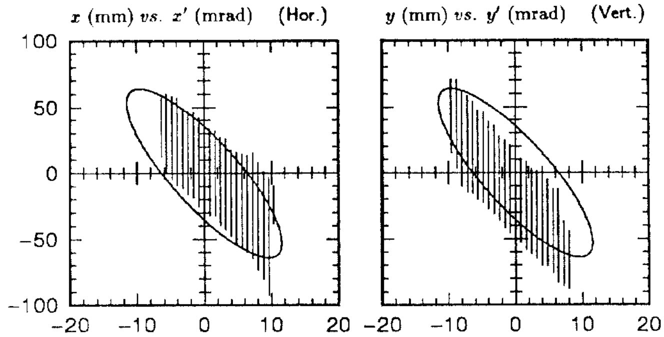

Figure 2. Emittance profiles of the input beam. The bars indicate measured profiles, and the ellipses the designed emittances matching to the RFQ acceptance ($\varepsilon_n = 0.6\ \pi$ mm·mrad).

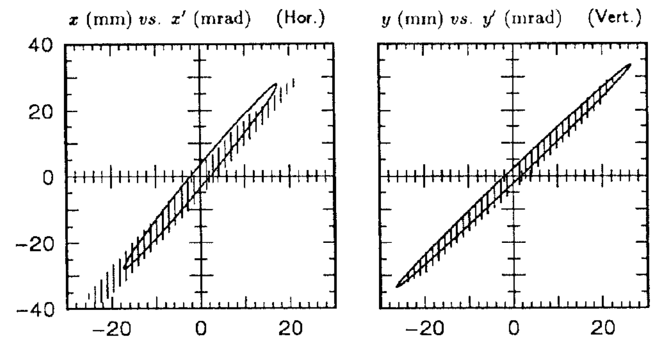

Figure 3. Emittance profiles of the output beam. The bars indicate measured profiles, and the ellipses the designed emittances ($\varepsilon_n = 0.6\ \pi$ mm·mrad).

The high-energy beam transport line was designed so as to measure the parameters of the output beam: beam currents of accelerated ions and unaccelerated ones, transverse emittances, kinetic energy and its spread. In the design, all the ions accelerated up to the design energy are focused into the Faraday cup 3 at the downstream end. For the energy-spread measurement, we set the slit in front of the Faraday cup and focus the beam onto it. The designed energy resolution $\Delta E/E$ is $\pm 0.34\%$, whereas PARMTEQ predicts an energy spread of $\pm 3.3\%$.

III. ACCELERATION TESTS

A. Emittance Measurements

Figure 2 shows measured profiles of the horizontal and vertical emittances of the input beam. The profiles are the ones at the rear slit of the emittance monitor 1; the slit position is 6.9 cm up the RFQ entrance. The bars indicate profiles cut off at a threshold level, 5% of the maximum density. The ellipses indicate the emittances matching the designed RFQ acceptance. The ellipse area is 411 π mm·mrad (the normalized emittance is 0.6 π mm·mrad). The matching between the beam emittance and the RFQ acceptance is not yet perfect: the beam is slightly off the axis. For better matching, devices for the beem steering will be soon installed.

Figure 3 shows the emittance profiles of the output beam at the rear slit of the emittance monitor 2. The slit position is 71.3 cm down the vane end. The ellipses are the designed emittances. The area is 61.0 π mm·mrad, and the normalized emittance is 0.6 π mm·mrad (the normalized 90%-emittances given by PARMTEQ are 0.458 π mm·mrad in the horizontal plane and 0.470 π mm·mrad in the vertical plane). The observed emittances have larger areas. This might be attributed to the input beam: it has ions out of the acceptance ellipses and contains ions other than N_2^+ ones.

B. Beam Energy

Figure 4 shows the currents of accelerated ions as functions of the current exciting the bending magnet, and demonstrates that the ions are accelerated to the design energy. The RFQ operated at an intervane voltage V_{vv} of 109.5 kV, or a normalized intervane voltage V_n of 1.07; $V_n \equiv V_{vv}(\text{operation})/V_{vv}(\text{design})$ (= 102.0 kV). In the figure, we present the results of four measurements for ion species: N_2^+, N^+, N^{++}, and H_2O^+. At each mesurement, the currents of the quadrupole magnets were adjusted so that all accelerated ions of the aimed species might be focused into the Faraday cup 3. The slit in front of the Faraday cup was fully opened; therefore, the signal widths do not mean energy spread.

From the signal heights, the numbers of ions are in the ratio of $N_2^+ : N^+ : N^{++} : H_2O^+ = 60 : 7 : 1 : 2$. Among the observed ions, N_2^+, N^+, and H_2O^+ were produced in the ion source, but N^{++} would be created through the dissociation process of accelerated N_2^+ ions, since the intervane voltage is so high ($V_n = 4.3$ for N^{++}) that the transverse motion of the ions is instable in the RFQ (PARMTEQ predicts no transmission). If the cross section for the dissociation process is in the order of 10^{-16} cm^2, the observed amount of N^{++} ions is reasonable.

Figure 5 shows energy profiles of accelerated N_2^+ ions.

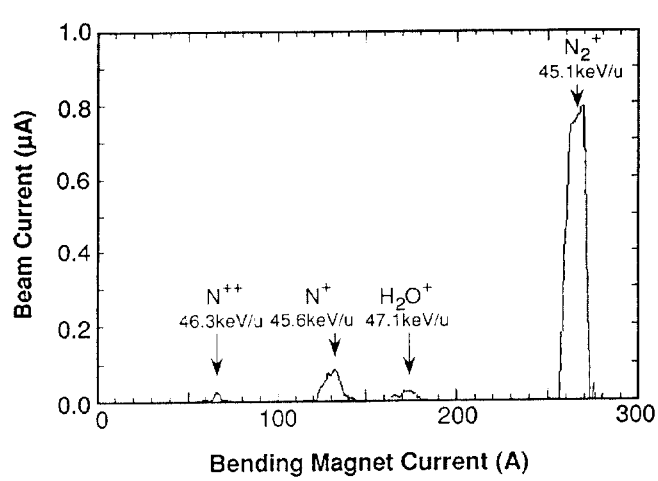

Figure 4. Beam currents measured with the Faraday cup 3 as functions of the bending-magnet current.

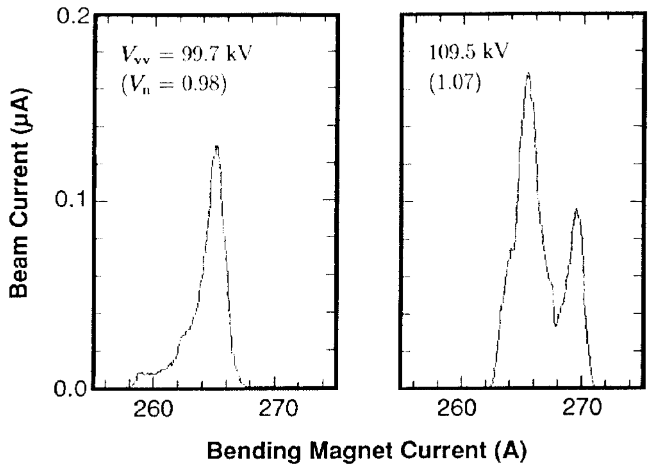

Figure 5. Energy profiles of accelerated N_2^+ ions.

In the measurements, the width of the horizontal slit in front of the Faraday cup 3 was set at ±3 mm (the estimated width of a monochromatic beam), and the intervane voltage was 99.7 kV (V_n = 0.98) or 109.5 kV (1.07). The observed full energy spreads are ±3.5% and ±3.1%, respectively. These values are almost same as PARMTEQ results.

C. Beam Transmission

The current of accelerated N_2^+ ions was measured as a function of intervane voltage. We use a notation I_i (i = 1, 2, 3) for a current measured with the Faraday cup i: I_1(all) = input beam current, comprising all of N_2^+, N^+, N^{++}, and H_2O^+ ions; I_2(all) = output beam current of accelerated and unaccelerated ions, comprising N_2^+, N^+, and H_2O^+ ions; $I_3(N_2^+)$ = current of accelerated N_2^+ ions.

Figure 6 shows current ratios $I_2(\mathrm{all})/I_1(\mathrm{all})$ and $I_3(N_2^+)/I_1(\mathrm{all})$ as functions of the normalized intervane voltage. At V_n = 1.1, the measured $I_3(N_2^+)/I_1(\mathrm{all})$ is 0.6. The transmission efficiency, defined by $I_3(N_2^+)/I_1(N_2^+)$, is estimated to be higher. From the current ratio presented in the subsection B and PARMTEQ calculations yielding $I_3(N^{++})/I_1(N^{++}) = 0$ and $I_3(N^+)/I_1(N^+)$, $I_3(H_2O^+)/I_1(H_2O^+) \simeq 0.5$, we infer $I_1(N_2^+)/I_1(\mathrm{all}) < 0.8$, and hence the transmission efficiency would be > 0.75.

The observed $I_3(N_2^+)/I_1(\mathrm{all})$ increases with the intervane voltage. PARMTEQ, however, predicts a steeper increase: for example, $I_3(N_2^+)/I_1(N_2^+) = 0.53$ at $V_n = 0.9$. Considering that the vanes were machined by means of the two-dimensional cutting technique (the transverse radius of curvature at the vane top is constant, $\rho_\perp = r_0$ = 0.946 cm), a possible reason for the slow increase is that, in the bunching stage, the longitudinal electric field actually generated by the vanes is weaker than that used in the PARMTEQ calculation. In other words, $A_{10} < A$. PARMTEQ uses the lowest-order two-term potential function [5]. The A parameter is the coefficient of the term that yields the longitudinal electric field. The potential function for the actual field, however, has additional higher order terms; the A_{10} term is the principal one that governs the longitudinal motion. In our RFQ, the ratio A_{10}/A varies from 0.7 to 0.8 in the bunching stage [6]. The separatrix would be accordingly smaller in the capture process; as a result, the transmission efficiency might have been reduced.

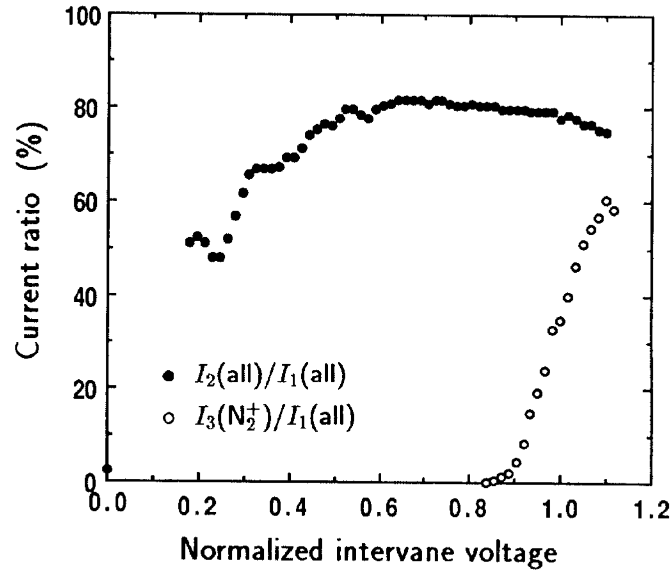

Figure 6. Current ratios $I_2(\mathrm{all})/I_1(\mathrm{all})$ and $I_3(N_2^+)/I_1(\mathrm{all})$ as functions of the normalized intervane voltage.

Acknowledgments

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