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PERFORMANCE OF THE RNB LINAC AT KEK-TANASHI

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Abstract

The performance of the RNB linac has been tested at KEK-Tanashi. The linac comprises a 25.5-MHz split coaxial RFQ and a 51-MHz interdigital-H (IH) linac. The test results are as follows: 1) the transmission of the RFQ is higher than 90% and that of the IH is nearly 100%, 2) the RFQ can accelerate ions with a charge-to-mass ratio from 1/2 to 1/30, 3) the IH can continuously vary the output energy in the range from 0.17 to 1.05 MeV/u, 4) the measured 2-rms 90% energy spreads are less than 2.4%, 5) the transmission for a $^{19}Ne^{2+}$ beam is about 80% and 6) the rf phase stability is within ±0.2°.

1 INTRODUCTION

A linac for radioactive nuclear beam (RNB) is working at KEK-Tanashi. The linac is a post accelerator in the ISOL-based RNB test facility. The radioactive nuclear beam extracted from the ISOL system is transported to the linac through a 60-m long beam line. The linac comprises a 25.5-MHz split coaxial RFQ with modulated vanes [1] and a 51-MHz interdigital-H (IH) linac [2], as shown in Fig. 1. Main specifications of the RFQ/IH linac are listed in Table 1.

The RFQ accelerates ions with a charge-to-mass ratio q/A greater than 1/30 from 2 to 172 keV/u. Duty factor of the RFQ is 100% at q/A>1/16, and $270\times(q/A)^2\times100\%$ at $1/17>q/A>1/30$. The cavity, 0.9 m in inner diam., comprises four unit cavities, each of which comprises three module-cavities. By using four 500-l/s turbo-molecular pumps, the cavity is kept at a vacuum of 5×10^{-7} Torr without power feed. We figure out the intervane voltage V from the monitor-loop voltage V_{ML} by using a relation, V/V_{ML}=10,388. The resonant resistance is 24.55±0.44 kΩ, and the input rf power for accelerating q/A=1/30 ions is nearly 240 kW.

Table 1: Main specifications of the RNB linac

	RFQ	IH	
Frequency (f)	25.5	51	MHz
Charge-to-mass ratio (q/A)	≥1/30	≥1/10	
Input energy (T_{in})	2	172	keV/u
Output energy (T_{out})	172	172-1053	keV/u
Normalized emittance (ε_n)	0.6 π		mm·mrad
Energy spread (ΔT)	1.03	<2.80	%
Mass number (A)	≤100		
RNB intensity	10^7-10^{10}		atoms/s
Duty factor	30	100	%
Repetition rate	20-1000		Hz
Total length	8.6	5.6	m

The IH linac accelerates ions with a q/A>1/10 up to 1.05 MeV/u, which comprises four tanks and three magnetic-quadrupole triplets between tanks. Since the tanks are excited separately by four rf sources, the output beam energy is continuously varied. The accelerating mode is π-π, and no transverse focusing element is installed in the drift tubes. The achieved effective shunt impedances of the 1st through 4th tanks are 264, 289, 268 and 218 MΩ/m, respectively. From the measured shunt impedances, we figured out the rf powers required for accelerating q/A=1/10 ions. The rf sources for the 1st through 4th tanks can supply 12, 22, 30 and 50 kW,

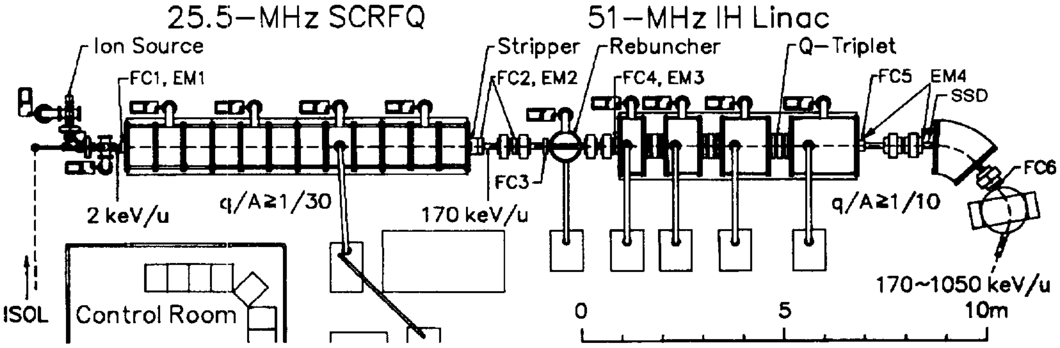

Figure 1: Layout of the RNB linac system.

respectively. Each of the 1st and 2nd tanks is evacuated by a 500-l/s turbo-molecular pump, and each of the 3rd and 4th tanks by a 1500-l/s pump. The obtained vacuum pressures are lower than 1×10^{-7} Torr without power feed.

2 BEAM ACCELERATION

2.1 Beam Transport and Diagnostics

The low-energy beam transport (see Fig. 1) comprises two beam lines from the ISOL and from a local ion source for stable nuclei. The local ion source is a compact ECR type excited by 2.45-GHz microwave. The line from the local ion source comprises a 90° bending magnet, two quadrupole magnets, and four einzel lenses. The momentum resolution of the ion separator is 0.65%.

We prepared three kinds of beam monitors: Faraday cup, emittance monitor and solid state detector (SSD). Faraday cups, FC1 through FC5, measure the beam current along the accelerator. They are equipped with a negative potential ring for suppressing the secondary electron emission. Double-slit emittance monitors, EM1 through EM4, are set before and behind the RFQ and IH linacs. An SSD is used to observe the energy spectrum.

The medium-energy beam transport between the RFQ and IH linacs comprises a charge stripper (carbon foil of 10 μg/cm^2), a 25.5-MHz rebuncher and two quadrupole doublets. The rebuncher is operated at a 100% duty factor. Total length of the transport is 3.76 m. The momentum-analyser in the high-energy beam transport comprises a quadrupole doublet, a dipole magnet, a 4-mm wide vertical slit, and a charge-collecting plate (FC6). We calibrated the momentum-analyser with the RFQ beam whose momentum was verified by means of time-of-flight measurement. The energy resolution is less than 1% for a 1-MeV/u ion beam with design emittance.

2.2 Transmission efficiency

The transmission efficiency of the RFQ was measured as a function of the intervane voltage by using N_2^+, N^+ and H_2^+ beams. Beam currents are measured with Faraday cups, FC1, FC2 and FC3. When the magnetic-field strength of the quadrupole doublet at the RFQ exit is sufficient to focus the accelerated ions into FC3, the transmission for the accelerated ions is obtained from I(FC3)/I(FC1), where I(FCi) is the beam current from Faraday cup i. The transmission for the drift-through ions (containing unaccelerated ions) is given by I(FC2)/I(FC1). The measured transmission is about 90% at design voltage and agrees well with PARMTEQ prediction. From Fig. 2, it was verified that the intervane voltage is applicable in a very wide range from 109 kV up to one fourteenth of that voltage.

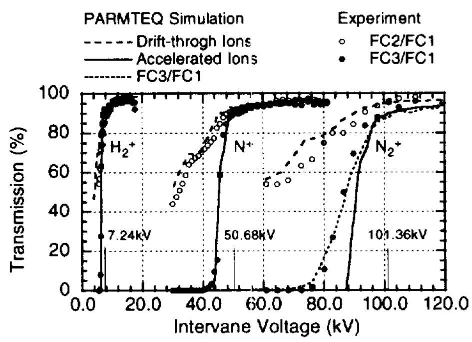

Figure 2: Transmission of the RFQ vs intervane voltage.

The transmission efficiency of the RFQ/IH linac was measured along the accelerator by using N^{2+} beam. The beam accelerated by the RFQ was directly injected to the IH linac without using the stripping foil. The measured result is shown in Fig. 3. The transmission of the RFQ is nearly 95% and that of the IH nearly 100%.

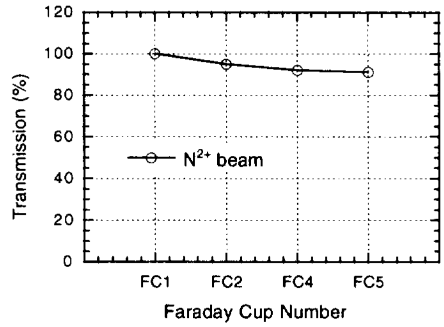

Figure 3: Transmission along the accelerator.

2.3 Energy and Energy Spread

We measured the output energy T and energy spread ΔT. Figure 4 shows the output energy spectra measured at six operating modes. The IH-tank4 energy agrees well with a designed one, 1.053 MeV/u. In Table 2, the measured T

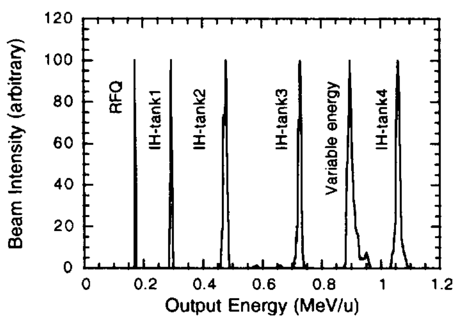

Figure 4: Energy spectra for six operating modes.

Table 2: Energy and its spread for six operating modes

	Output energy T (keV/u)		Energy spread $\Delta T/T$ (%)	
RFQ	172	(172)	1.56	(1.03)
IH-tank1	293	(295)	1.65	(2.80)
IH-tank2	476	(476)	1.97	(2.79)
IH-tank3	726	(728)	1.15	(1.45)
Variable	900	(879)	2.32	(2.08)
IH-tank4	1059	(1053)	1.12	(1.17)

and ΔT values are compared with calculated values in parentheses. ΔT is defined by 2-rms of the spectrum containing 90% ions. The measured energy spreads are smaller than calculated ones except for the RFQ mode.

2.4 Transverse Emittance

The emittance profiles of N^{2+} beam (see Fig. 5) were measured at the RFQ entrance, RFQ exit, IH entrance and IH exit. The bars show the measured 90% emittance profiles, the solid-line ellipses the design ones with an ε_n= 0.06 π cm·mrad, and the broken line ellipses the design ones with a normalized acceptance of 0.24 π cm·mrad.

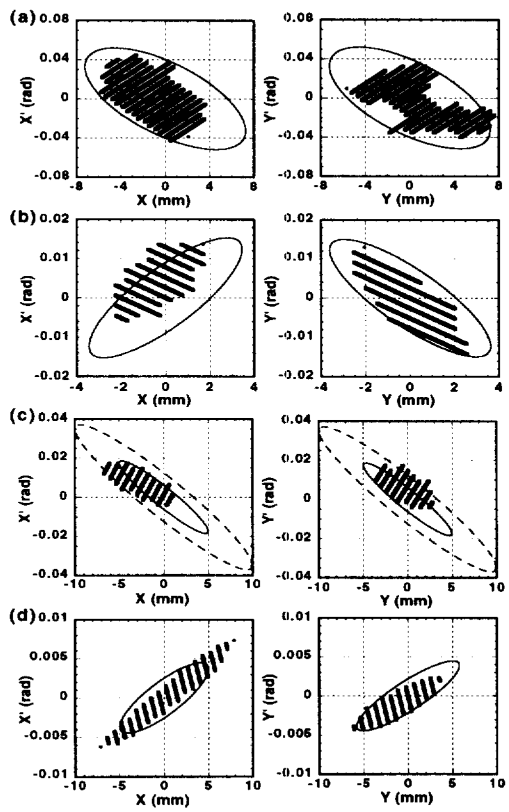

Figure 5: Emittance profiles at (a) RFQ entrance, (b) RFQ exit, (c) IH entrance and (d) IH exit.

2.5 Different Accelerating Modes

The linac is operated at different accelerating modes to change the output energy. The IH-tank2 energy in Fig. 4

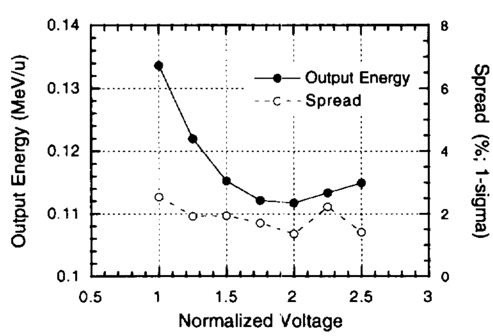

Figure 6: Energy and its spread vs normalized voltage.

was obtained by cutting off the rf power to the tank3 and tank4, and a variable energy by adjusting the rf voltage and phase in tank4. Deceleration test of the RFQ beam was conducted by using the IH-tank1, to extend the variable-energy range. In the experiment, He^{+} beam was injected at a decelerating phase of 135°, and the output energy and its spread were measured as a function of the rf voltage. Figure 6 shows the minimum energy is 112 keV/u at a normalized voltage of about 1.8.

2.6 Acceleration of the RNB

The acceleration test of $^{19}Ne^{2+}$ with a half life of 17.3 s was conducted. The ^{19}Ne nuclei produced by bombarding a LiF+C target with 30 MeV-protons from the SF cyclotron were ionized in an ECR ion source. The accelerated energy was 0.72 MeV/u. The transmission efficiency of the RFQ/IH linac was about 80%. We measured the beam intensity by counting the 511-keV γ-rays emitted by β^{+}-decay with Ge or CsI detector. The $^{19}Ne^{2+}$ intensity measured by a Ge detector at the secondary target position was 8.8×10^{4} atoms/s.

3 RF STABILITY

To compensate the resonant-frequency shift of the cavity due to the temperature change, we developed a piston-tuner control system. The piston tuners are moved automatically so as to minimize the reflected power from the cavity. The control system comprises the circuits for reading the reflected power levels, the tuner driver circuits, and a personal computer.

The rf-power sources have the automatic gain and phase control system, in which the feedback signal is picked up from the forward power to the cavity. As for the forward power, voltage variation is within ±0.25%, and phase one within ±0.2°. However, we can not ignore the phase variation in the cavity due to the temperature change. We added a feedback system for constantly keeping the phase difference between different cavities. The test result shows the phase stability is within ±0.2°.

4 CONCLUDING REMARKS

The test results showed the performance of the RNB linac was close to the designed one. By improving the rf stability, good experimental data will be obtained. We express our thanks to T. Nomura and E-group members for their support.

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