2a2-3

PROGRESS REPORT ON THE CONSTRUCTION OF THE HEAVY-ION LINACS FOR RADIOACTIVE NUCLEI

M. Tomizawa, S. Arai, Y. Arakaki, Y. Hashimoto, A. Imanishi, T. Katayama, H. Masuda, K. Niki, M. Okada, Y. Takeda, E. Tojyo, N. Tokuda, C. Velissaris, K. Yoshida, and M. Yoshizawa

Institute for Nuclear Study, University of Tokyo
3-2-1 Midori-cho, Tanashi, Tokyo 188, Japan

Abstract

A heavy-ion linac complex for radioactive beams is now under construction at INS. The linacs are a 25.5-MHz split coaxial RFQ and a 51-MHz interdigital-H (IH) linac. Ions with a charge-to-mass ratio (q/A) greater than 1/30 are accelerated from 2 to 172 keV/u by the RFQ. The beam passes through a carbon-foil, and ions with $q/A \geq 1/10$ are accelerated further by the IH linac. The output energy is variable in the range of 0.17 through 1.05 MeV/u. The RFQ has already accelerated stable ions, Ne^+ and N^+. The IH linac has undergone low-power tests. Other devices in the beam transport line between the linacs are under fabrication or tuning. The first beam acceleration through the linacs is scheduled for March, 1996.

1. Introduction

A radioactive-beam facility is now under construction at INS. The beam from an isotope separator online (ISOL) will be accelerated by a 25.5-MHz RFQ and a 51-MHz interdigital-H (IH) linac, and used for nuclear physics experiments.

Figure 1 shows the layout of the linac system. The RFQ accelerates ions with a charge-to-mass ratio (q/A) greater than 1/30 from 2 to 172 keV/u. The output beam is enhanced in charge state in a carbon-foil stripper ($q/A \geq 1/10$), and then shaped in the longitudinal and transverse phase spaces by a 25.5-MHz rebuncher and 2 doublets of quadrupole magnets. The IH linac consists of 4 tanks and 3 triplets of quadrupole magnets between tanks. The tanks are excited separately by 4 rf power sources, and hence, it is possible to vary the output beam energy continuously in the range from 0.17 to 1.05 MeV/u by adjusting the rf power levels and phases.

In Fig.1, the ion source, low-energy beam transport, RFQ, and the first quadrupole doublet came into operation in March, 1995. The RFQ, whose parameters are given in Table 1, accelerated stable ions Ne^+ and N^+. The ion source was a 2.45-GHz ECR one located near the RFQ. The measured transmission efficiencies and emittance profiles of the output beam agreed well with PARMTEQ predictions.[1] The IH tanks have undergone low-power tests: tuning of the resonant frequency, measurement of the Q-values, bead-pull measurement of the field distributions in the accelerating gaps, and evaluation of the shunt impedances. Similar low-power tests have been conducted on the rebuncher cavity, which is a folded coaxial-line resonator with 6 gaps.[2] The second quadrupole doublet is now being fabricated.

The linac system will be completed in March, 1996. Then the first beam acceleration through the linacs will be conducted.

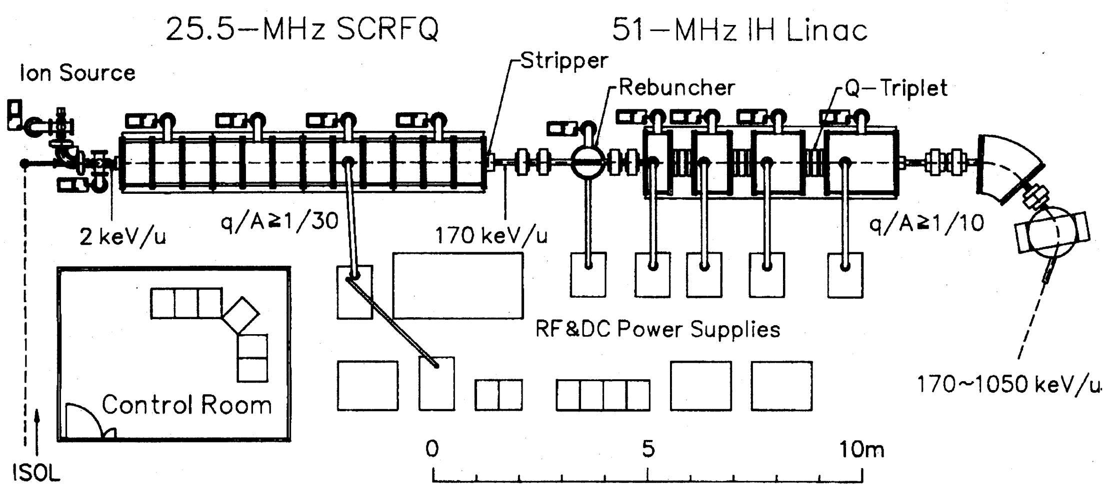

Figure 1: Heavy-ion linac system under construction.

Table 1
Design parameters of the RFQ.

Frequency (f)	25.5 MHz
Charge-to-mass ratio (q/A)	1/30
Kinetic energy $(T_{in} \rightarrow T_{out})$	$2 \rightarrow 172$ keV/u
Normalized emittance (ε_n)	$0.06\,\pi$ cm·mrad
Vane length (L_v)	858.5 cm
Number of cells (N_c)	172
Intervane voltage (V_{vv})	108.6 kV
Maximum surface field $(E_{s,max})$	178.2 kV/cm (2.49 Kilp.)
Mean aperture radius (r_0)	0.9846 cm
Minimum aperture radius (a_{min})	0.5388 cm
Max. modulation index (m_{max})	2.53
Final synchronous phase (ϕ_f)	$-30°$
Transmission (0 mA input)	91.4%

2. Split Coaxial RFQ

During the beam tests conducted in April, transmission efficiencies were measured for various intervane voltages.[1)] The ion was N^+, and the input beam current was $0.21 \sim 0.22$ mA in peak (duty factor was $5\% = 0.53$ ms $\times$ 95 Hz). At the nominal voltage (V_{vv} = 50.68 kV), 90% of the injected ions were accelerated; 91.4% is the PARMTEQ value. Good agreements between the experimental data and simulation predictions were obtained also at higher intervane voltages; the maximum was 81 kV. At $V_{vv} = 81$ kV, the rf peak power (P_{peak}) and the averaged one (P_{ave}) were 134 kW and 6.7 kW, respectively. At such a P_{ave} level or lower, the RFQ has a good performance; this is our conclusion for the beam tests.

We aim at operating the RFQ at higher power levels. The issues are to keep the resonant frequency under control and to verify that the vanes are well cooled. If they are distorted by heat, the beam performance obtained at the lower powers would not be preserved. We have been trying to raise the intervane voltage to 109 kV (design value for $q/A = 1/30$ ions), and the duty factor to 30%. As shown in Table 2, the duty factor is still lower, but the intervane voltage has almost reached the goal.

3. Interdigital-H Linac

Table 3 lists main parameters of the IH linac. The output energy is variable in the range of 0.17 through 1.05 MeV/u. Figure 2 shows a simulation result of the energy spread as a function of the output energy. The levels and phases of the rf powers into the tanks are optimized so that the energy spread might be minimized. The input beam is a simulated C^{3+} one that has passed all the elements before the IH linac (a 10-μg/cm^2 carbon-foil stripper is included). The input energy is 167 keV/u, and the full widths of the phase and energy spreads are 35° and 1 keV/u. Resultant energy spreads at the output are $\pm 0.85\%$ at 0.7 MeV/u, and $\pm 0.45\%$ at 1 MeV/u. Without the stripper the energy spreads are 3/4 of these values.

Table 2
Progress in feeding high power into the RFQ.

Date	V_{vv} (kV)	P_{peak} (kW)	P_{ave} (kW)	duty (%)	width (ms)	rep. (Hz)
3/22/95	81	134	26.5	19.8	0.66	300
4/13/95	91	170	2.6	1.5	0.53	29
6/20/95	104	220	13.2	6.0	0.50	120
7/12/95	107	242	6.1	2.5	0.50	50
9/05/95	108	235	18.8	8.0	2.00	40
goal	109	242	72.6	30.0		

Table 3
Main parameters of the IH linac.

	Tank 1	Tank 2	Tank 3	Tank 4
f (MHz)	51	51	51	51
q/A	$\geq 1/10$	$\geq 1/10$	$\geq 1/10$	$\geq 1/10$
T_{out} (keV/u)	294	475	725	1053
L_{tank} (cm)	68	90	116	153
D_{tank} (cm)	149	149	149	134
R_{bore} (cm)	1.0	1.2	1.4	1.6
$D_{d.tube}$ (cm)	3.8	4.4	4.6	5.2
No. of cells	9	10	11	12
$\overline{E}_{acc}$ (MV/m)	2.10	2.15	2.17	2.14

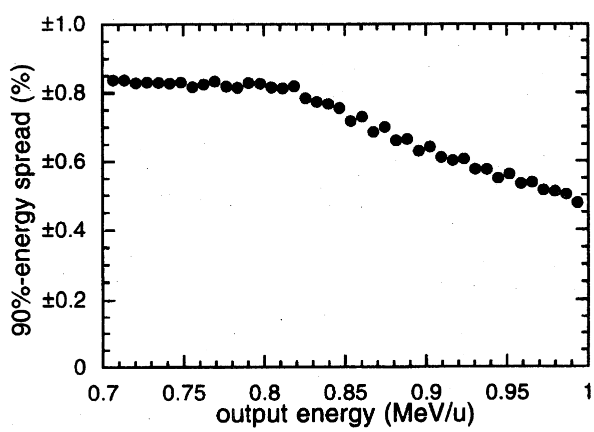

Figure 2: Energy spread vs output energy.

We had fabricated a cold model for each of the 4 tanks, and studied the rf characteristics of the IH cavity.[3,4)] The models were scaled up to the present IH tanks; the scale factors are 20/9 at Tanks $1 \sim 3$, and 2 at Tank 4. Low-power tests of the tanks have been almost finished. The results are summarized in Table 4. Every tank was matched to a 50-Ω signal generator via a loop coupler. It was attached to a port placed near a ridge end. Before the tuning, Tanks $1 \sim 3$ had resonant frequencies ($f_{initial}$ in Table 4) higher than 51 MHz by 84, 134, and 180 kHz, respectively. We decreased the frequencies closer to 51 MHz (f_{tuned}) by using capacitive tuners: every tank has a C-tuner, which is a movable disk (19 cm dia) facing a ridge.

Table 4
Summary of low-power tests of the IH tanks.

	Tank 1	Tank 2	Tank 3	Tank 4
f_{initial} (MHz)	51.084	51.134	51.180	51.003
f_{tuned} (MHz)	51.003	51.007	51.057*	51.000
Q_{unloaded}	10681	15387	15758*	18490
	11077†	11602†	13462†	14541†
Z_{eff} (MΩ/m)	264	289	249*	218
	247†	219†	211†	179†
P (kW)	10.5	15	27*	39
ΔV_{gap} (%)	±2.0	±2.9	±4.2*	±2.2

* : preliminary, † : estimated from cold-model tests.

Figure 3 shows the results of bead-pull measurements. An aluminum sphere (6 mm dia) was moved along the beam axis. We obtained gap-voltage distributions almost flat except at the tank ends (see also ΔV_{gap} in Table 4) without any particular tuning for the flatness. From the measured unloaded Q-values and field distributions in the gaps, we figured out effective shunt impedances (Z_{eff}).

The estimated rf powers (P) required for the acceleration of $q/A = 1/10$ ions up to 1.05 MeV/u are lower than the capacities of the power sources. Their nominal maximum powers in cw operation are 12 kW (Tank 1), 22 kW (Tank 2), 30 kW (Tank 3), and 50 kW (Tank 4). The stabilities in power and phase were measured. Table 5 lists the results obtained from cw operations with a dummy load. The measurement lasted for 1 ~ 1.5 hours after aging of 4 ~ 6 hours.

Table 5
Stabilities of the power sources for the IH tanks.

Source	P_{out} (W)	$\Delta P_{\text{out}}/P_{\text{out}}$ (%)	$\Delta\phi$ (deg)
No. 1	12,000	±0.24	±0.1
(for Tank 1)	120	±0.1	±0.1
No. 2	22,000	±0.1	±0.2
(for Tank 2)	220	±0.2	±0.1
No. 3	30,000	±0.3	±0.15
(for Tank 3)	300	±0.4	±0.15
No. 4	50,000	±0.4	±0.1
(for Tank 4)	500	±0.5	±0.15

4. Acknowledgments

We express our thanks to T. Nomura for his encouragement. The IH linac was fabricated by Sumitomo Heavy Industries, Niihama Work, and the IH power sources by IDX Corporation.

References

[1] S. Arai *et al.*, "First Beam Tests of the INS Split Coaxial RFQ for Radioactive Nuclei", 1995 Part. Acc. Conf. and Int. Conf. on High-Energy Acc., Dallas, Texas, U.S.A., May, 1995.

[2] Y. Hashimoto *et al.*, "Cold test of a 25.5 MHz Double-Coaxial $\lambda/4$ Resonator", this symposium.

[3] M. Tomizawa *et al.*, "Construction of an Interdigital-H linac at INS", 4th European Part. Acc. Conf., London, England, June, 1994.

[4] M. Tomizawa *et al.*, "Model Measurement and Present Status of Interdigital-H Linac at INS", 17th Int. Linac Conf., Tsukuba, Japan, 1994.

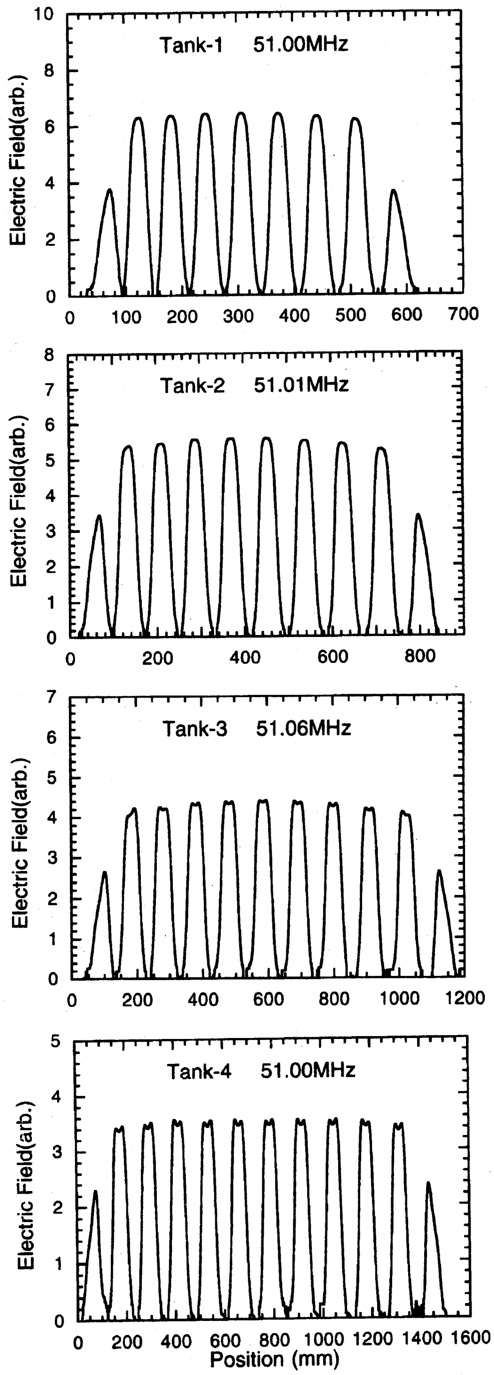

Figure 3: Electric field distributions along the beam axes of the IH tanks.