PROGRESS REPORT OF THE INTERDIGITAL-H LINAC FOR RADIOACTIVE NUCLEI AT INS

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Abstract

In a radioactive-beam facility at INS, unstable nuclei with a charge-to-mass ratio (q/A) greater than 1/10 are accelerated from 170 to 1053 keV/u by an interdigital-H(IH) linac. The IH linac consists of four acceleration tanks and three sets of quadrupole triplets placed between the tanks. The output energy is continuously variable by changing rf power and phase of the operating tank. Low power and high power tests were performed on the constructed IH cavities. In the first acceleration test using a stable nuclear beam N^{2+} beam, we succeeded to accelerate the beam up to the designed energy. Further beam tests will be done to obtain better transmission and beam quality.

1 INTRODUCTION

In a radioactive-beam facility at INS, unstable nuclei produced by bombarding a thick target with 40 MeV proton beam ($\sim 10\mu$A) from the existing SF cyclotron are ionized in ion sources, mass-analyzed by an Isotope Separator On Line (ISOL), and transported to an accelerator complex [1]. The accelerator complex consists of a 25.5 MHz-SCRFQ (split coaxial RFQ), a 51 MHz-IH (interdigital-H type) linac and a matching section between the SCRFQ and the IH linac [2, 3, 4].

The IH linac comprises four tanks and three sets of quadrupole triplets placed between the tanks. Main parameters of the IH linac are listed in Table 1. The output energy is continuously changed by tuning rf power and its phase of the last operating tank [5]. Optimum set of the gap voltage and the phase was searched by a simulation so as to obtain the minimum energy spread for the given output energy. Particles traced from an entrance of the SCRFQ were used as an initial condition at an entrance of the IH linac (including a 10 μg/cm^2-carbon stripper). Figure 1 shows the minimum energy spread and the phase spread(upper), and sets of the gap voltage and the rf phase(lower). About 80$\sim$90 % particles are within $\pm$ 2σ (rms) width of the energy spread(ΔT/T) or the phase spread($\Delta\phi$).

Table 1: Main parameters of IH linac

	tank1	tank2	tank3	tank4
f(MHz)	51	51	51	51
max. q/A	1/10	1/10	1/10	1/10
T_{out}(MeV/u)	0.294	0.475	0.725	1.053
L_{tank}(m)	0.68	0.90	1.16	1.53
D_{tank}(m)	1.49	1.49	1.49	1.34
D_{bore}(cm)	2.0	2.4	2.8	3.2
D_{tube}(cm)	3.8	4.4	4.6	5.2
L_{gap}(cm)	2.9	3.7	4.5	5.3
Cell No.	9	10	11	12

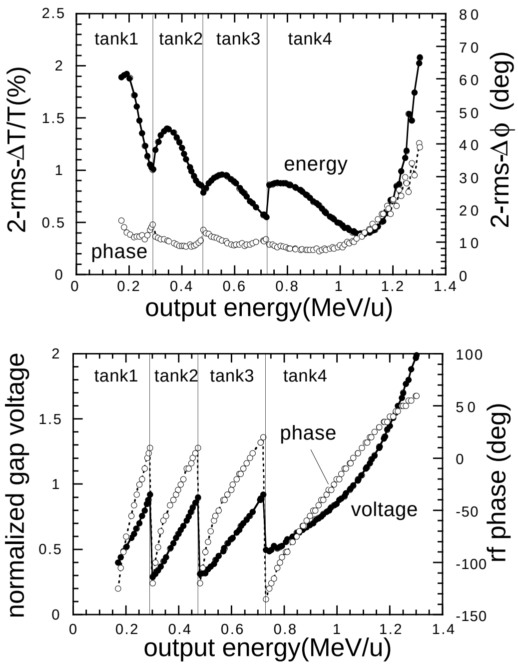

Figure 1: Upper part is the minimum energy spread and the corresponding phase spread at the exit of the each tank as a function of the output energy. Lower one is the gap voltage and the rf phase to give the minimum energy spread (the rf phase 0 means that particles are injected in a synchronous phase(-25°).

2 LOW POWER MEASUREMENT

The acceleration tanks were constructed on the basis of the study using cold models. Q-values and field distributions of the tanks were measured in atmosphere after installation on the beam line. Coupling loops were rotated so as to minimize a power reflection (50Ω-matching). Table 2 shows a summary of the low power measurements. Figure 2 shows the gap voltage distributions measured by a bead-pull method. We obtained almost flat gap voltage distributions except at the tank ends without any particular tuning for the flatness. Effective shunt impedances (Z_{eff}s) were obtained from the results of these measurements. The estimated rf powers 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.

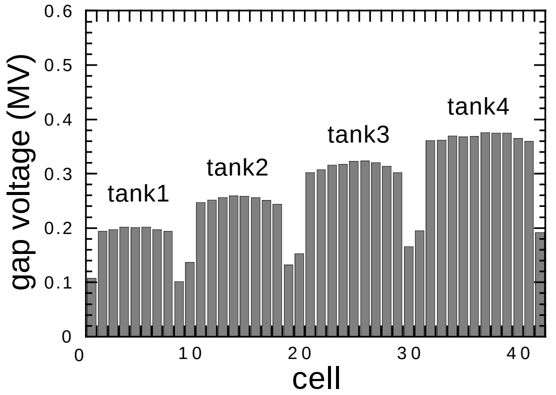

Figure 2: Gap voltage distributions measured by a bead-pull method. The gap voltage is given by the nominal maximum one.

Table 2: Summary of low power tests of IH linac

	tank1	tank2	tank3	tank4
$Q_{unloaded}$	10681	15387	16230	18490
Z_{eff} (MΩ/m)	264	289	268	218
Power (kW)	10.5	15	25	39

3 HIGH POWER TEST

An rf power is independently fed to each tank. Nominal maximum powers of the rf sources are 12kW (tank1), 22kW (tank2), 30kW (tank3) and 50kW (tank4). The duty can be varied by changing a pulse width(50μsec∼3msec) and a repetition rate (100∼1000 Hz). Stability in the output power and the phase was measured by using 50 Ω dummy loads. The results are reported in Reference [6]. The rf sources were connected to the tanks through about 20-meter-long coaxial tubes (WX-77D for the tank1 through tank3, WX-120D for the tank4).

Each of the tank1 and the tank2 is evacuated by a 500 ℓ/sec-turbo molecular pump, and each of the tank3 and the tank4 is by a 1500 ℓ/sec one. The obtained vacuum pressures are in the range of 10^{-7} torr under no power feed.

The high power aging was planned in the following two steps. The first one is for the scheduled first beam experiment, in which 70% of the maximum gap voltage and 10% in a duty are required. The second one is to achieve the 100% duty factor and the designed maximum gap voltage. In this test, the former aging was performed. The aging was successfully completed for four cavities. The aging history is shown in Figure 3. The needed aging time (the duty∼ 20%) was 10∼12 hours per a cavity.

The intensity of X-rays emitted from the cavities was measured by a NaI-survey meter. The intensity increased with the input power, especially, the X-rays emitted from the tank4 amounted to 5 μSv/h at the distance of 1.5 m from the the tank wall.

The energy spectra of emitted X-rays were measured by a Ge-detector. The edge energy of the peak should be same as the gap voltage (V_{x-ray}). The gap voltage (V_{bead}) is also estimated from the Z_{eff} and the input rf power obtained by a bead-pull method. The ratios V_{x-ray}/V_{bead} were 0.99,0.93,1.11 and 1.05 for the tank1∼tank4, respectively.

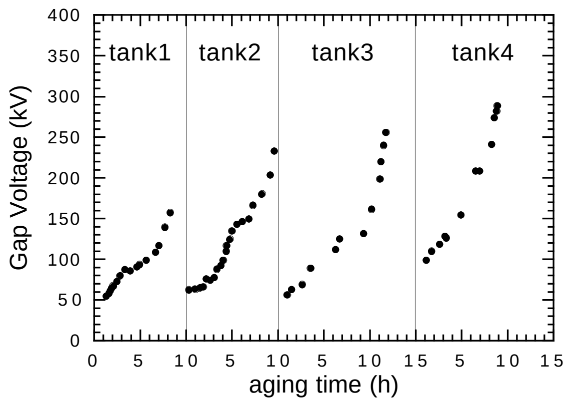

Figure 3: Aging history of the IH linac.

4 FIRST BEAM TEST

First beam test of the IH linac was performed in the spring of 1996. Figure 4 shows a layout of the linac complex. A 2.45 GHz-ECR ion source was used to produce the N^{2+} beam (q/A=1/7). The N^{2+} beam intensity at the entrance of the SCRFQ is about 1 μA at peak in a pulse operation, 0.6 msec in width and 100 Hz in repetition rate. The rf pulse widths of the SCRFQ and the IH linac were set to 1 msec so as to cover the beam pulse from the ion source. The 25.5 MHz-rebuncher placed between the SCRFQ and the IH linac was operated at 100% duty. The beam accelerated by the SCRFQ was directly injected to the IH linac without using the stripping foil. The accelerated beam by the IH linac was momentum-analyzed by a quadrupole doublet and a bending magnet placed downstream of the IH linac. The analyzed beam intensity was measured by a beam-slit and a plate placed downstream of the bending magnet. The beam energy was estimated from the magnetic field measured by a hole probe. Figure 5 shows the analyzed beam intensity for four operating modes. For example, "tank3" in the figure shows that the SCRFQ and the IH-tank1 through tank3 are operated and the tank4 is not operated. As seen from "tank4" in the figure, the beam was accelerated up to 1.05 MeV/u (designed maximum value).

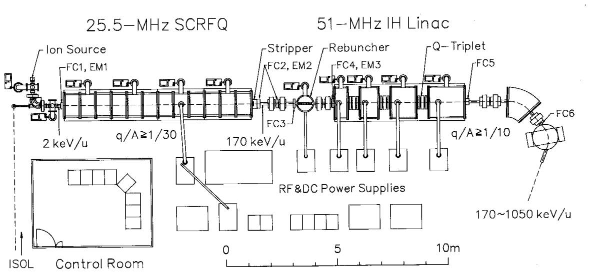

Figure 4: Layout of the linac complex.

The width of the peaks depends on the beam optics as well as the energy spread. Further investigation on the beam optics is needed to obtain the energy spread exactly from this method. The obtained transmission efficiencies are lower compared with the designed value. We expect that the transmission will be improved by setting longitudinal(rf amplitude and phase) and transverse(quadrupole strength) parameters at optimum values by the following methods.

- In this IH linac, longitudinal beam parameters (output energy, its spread and phase spread) are sensitive to the rf power and the rf phase relation between tanks. It is important to set these parameters to the designed values. Figure 6 shows the dependence of the output energy on the rf phase predicted from a simulation. They were calculated for the normalized gap voltage of Vg=0.9,1.0 and 1.1(Vg=1 is the designed value). If the beam with the designed energy is injected, we can know the generated gap voltage by comparing the measured maximum energy with the simulated one. Next we set the gap voltage to the valid value and measure the output energy as a function of the phase. As a result, we can set the rf phase to give the nominal output energy.
- The emittance monitors are equipped the entrance and the exit of the IH linac. We can set the quadrupole parameters to obtain the valid values from the measured emittances.

5 ACKNOWLEDGMENTS

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6 REFERENCES

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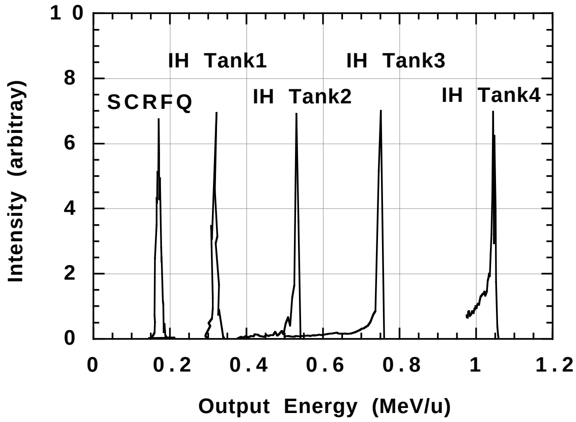

Figure 5: Momentum analyzed beam for five acceleration modes.

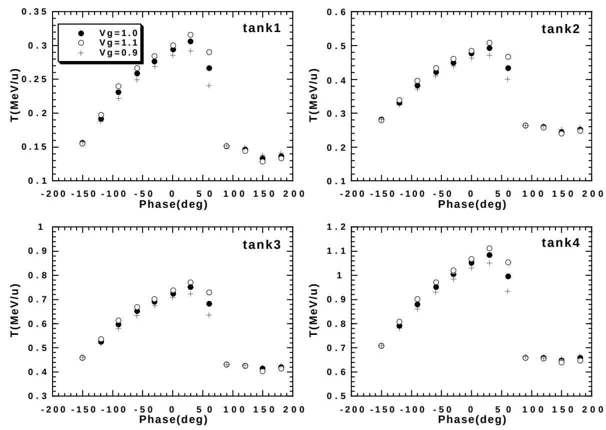

Figure 6: Dependence of the output energy on the rf phase (by a simulation).

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