Interdigital-H Linac for Unstable Nuclei at INS

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Abstract

In the prototype facility of the Exotic-arena at INS, unstable nuclei with a charge-to-mass ratio greater than 1/10 is accelerated from 170 to 1046 keV/u by an intergiditai-H linac. Designed IH linac consists of four acceleration tanks and three sets of quadrupole triplets placed between tanks. Output energy is continuously variable by changing rf power and phase of the last operating tank. A high shunt impedance is expected from an equivalent circuit analysis. The rf measurement on the low power models is now in progress. Preliminary results of the tank-4 model shows that a resonant frequency and a shunt impedance roughly agree with the design values.

I. INTRODUCTION

The construction of the prototype facility of the Exotic-arena proposed in the Japanese Hadron Project(JHP) started at INS in 1992[1-3]. In this facility, unstable nuclei accelerated up to 170 keV/u by a split coaxial RFQ is charge-exchanged by a stripper up to a charge-to-mass ratio (q/A) greater than 1/10, and further accelerated by an interdigital-H linac[4,5]. Design of the interdigital-H (IH) type linac has been performed in 1992. Designed IH linac has the following characteristics. (1) It accelerates the heavy ions from low energy (170 keV/u). (2) Synchronous phase is selected as -25 deg to assure the stable longitudinal motion in spite of the strong transverse rf defocusing force in the accelerating gaps. (3) To obtain high acceleration efficiency, a π-π mode is adopted as a periodic structure, and no transverse focusing element is installed in the drift tubes. (4) The IH linac is divided into four tanks. Transverse focusing elements are placed between tanks. (5) The output energy is continuously variable from 170 to 1046 keV/u by tuning the rf power and phase.

The view of the designed IH linac is shown in Figure 1. The parameters of the designed IH linac are listed in Table 1.

II. BEAM DYNAMICS

The resonant frequency of the IH linac is chosen to be twice as high as that of the SCRFQ. To keep the phase spread small, the length of drift spaces where Q-magnets are placed should be as short as possible. The length of the drift spaces is taken to be 47.5 cm. In this case, longitudinal acceptance of 200π keV/u•deg is obtained, which is nearly three times as large as the predicted beam emittance from the SCRFQ. The transverse emittance of the unstable nuclei is small, estimated to be less than 0.1π mm•mrad[6]. But an acceptance larger than this value is required because of an emittance growth at the charge stripper. The acceptance of 2.4π mm•mrad (transmission 97%) is achieved by setting the bore radius of quadrupole magnets at 20 mm (the emittance of the SCRFQ is estimated to be 0.6π mm•mrad). Figure 2 shows the calculated longitudinal and transverse beam traces. In this calculation, longitudinal and transverse emittance at the entrance of the tank-1 are taken to be 200π keV/u•deg and 1.7π mm•mrad, respectively.

The output energy of the IH linac can be continuously varied by tuning the rf power and phase in the last tank of operating ones. The variation of output energies results from separating the IH linac into several tanks. Figure 3 shows the output energy and its spread as a function of the gap voltage. Longitudinal emittance at the entrance of the tank-1 is taken to be 200π keV/u•deg. For example, if a certain energy in the range from 471 to 721 keV/u is needed, the gap voltage of tank-3 is varied without operating tank-4. The energy spread ($\pm\Delta T/T$) is ±2~6% except at the exit of tank-1. Its spread, however, can be made smaller by adjusting the rf phase as well as the gap voltage.

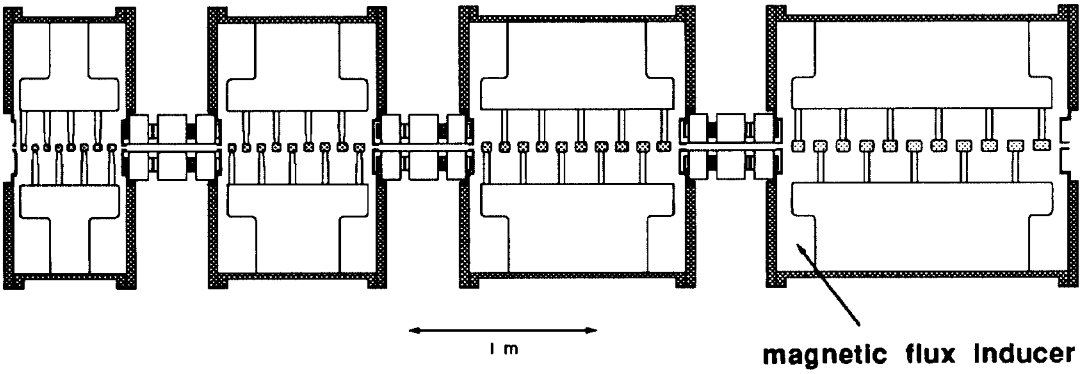

Fig.1 View of the desined IH linac.

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Table 1 Parameters of designed IH linac.

	tank-1	tank-2	tank-3	tank-4
resonant frequency (MHz)	51	51	51	51
charge-to-mass ratio	≥ 1/10	≥ 1/10	≥ 1/10	≥ 1/10
energy (keV/u)	170 ~ 292	292 ~ 471	471 ~ 721	721 ~ 1046
velocity β (%)	1.91 ~2.50	2.50 ~ 3.18	3.18 ~ 3.93	3.93 ~ 4.74
synchronous phase (deg)	-25	-25	-25	-25
tank diameter (m)	1.34	1.34	1.34	1.34
tank length (m)	0.59	0.84	1.15	1.53
cell number	9	10	11	12
acceleration gradient (MV/m)	2.73	2.73	2.72	2.65
effective shunt impedance (MΩ/m)	751	510	345	244
maximum peak power (kW)	5.1	11	22	40

III. QUADRUPOLE MAGNETS

To obtain large transverse acceptance, the bore radius of quadrupole magnets was chosen to be 20 mm. High field gradient (5.5 kG/cm at maximum) is required to focus the beam. Further, compact sizes are required to be placed in the 47.5 cm long drift space. Design of the quadrupole magnets was performed by the computer code TRIM. The parameters of the quadrupole magnets are shown in Table 2. To obtain high field gradient, pure iron with a low amount of carbon will be used as the material of poles and yokes. From the calculation, 10000 A•T is necessary to attain the field gradient of 5.5 kG/cm. To save the cost of the power supplies, the size of hollow conductors used as the coils of magnets was chosen to keep the maximum current in 300A. As a result, the coil has two lines for water cooling per pole. One set of the quadrupole triplets is now under construction. Effects of the adjacent quadrupole magnets and the saturation of the magnetic field in the pole will be investigated by field measurements.

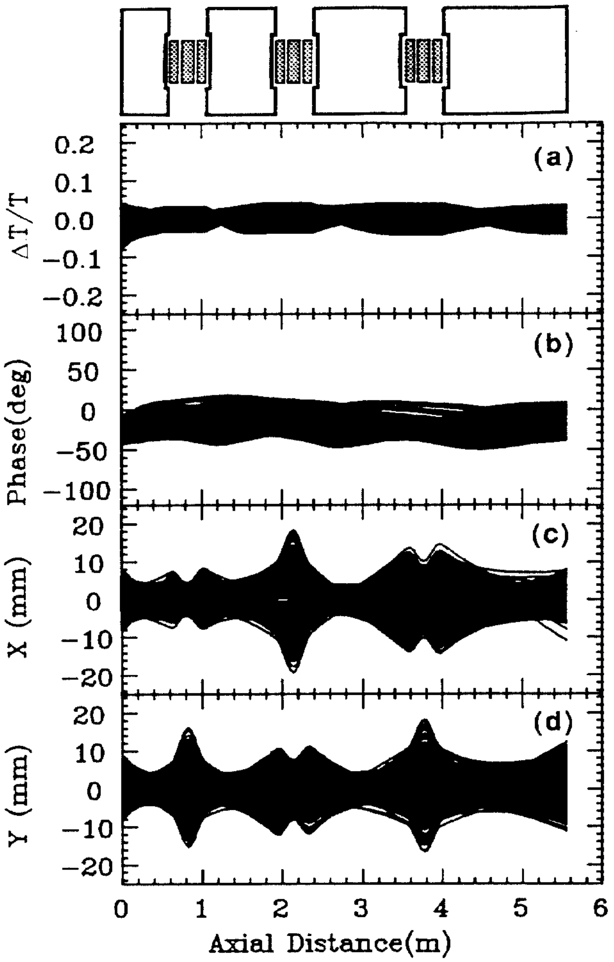

Fig.2 Calculated beam profile.

IV. RF CAVITY

A. Cavity Design

Axial length of the four cavities is shorter than or near the diameter needed for resonant frequency of 51 MHz. To estimate the resonant characteristics, an equivalent circuit analysis was performed. In this analysis, the capacitance in each cell was partially calculated by the computer code SUPERFISH. The inductance of each cell was approximately obtained by assuming uniformity of the magnetic flux[7]. The equivalent circuit composed of these cells is terminated by a circuit composed of the capacitance and inductance of end

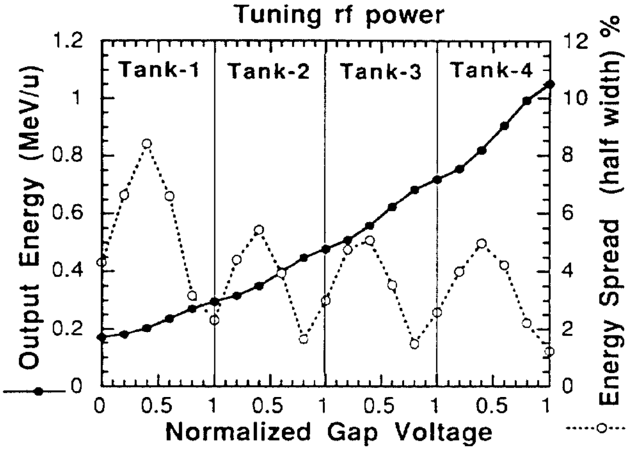

Fig.3 Output energy and its spread as a function of normalized gap voltage.

Table 2 Design parameters of quadrupole triplet.

	QS 1	QL	QS 2
bore radius (cm)	2	2	2
pole length (cm)	9	14	9
max. B' (kG/cm)	5.5	5.5	5.5
max. current (A)	300	300	300
max. power (kW)	9.3	11.2	9.3

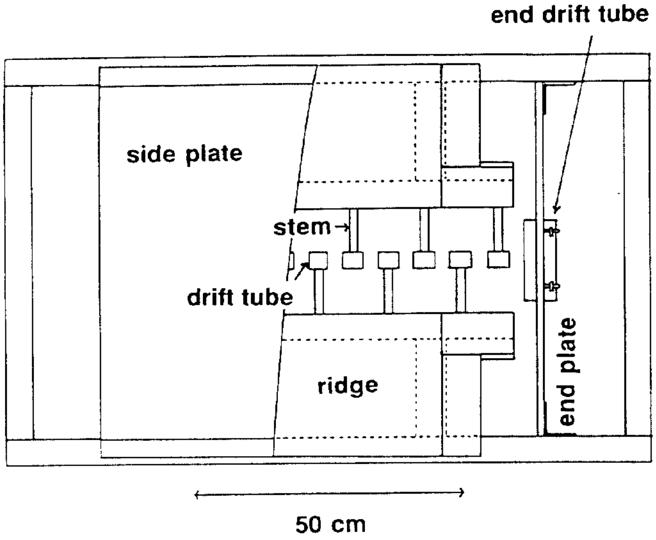

Fig.4 1/2 scale model of the tank-4.

spaces. In our case, the end capacitance as well as the end inductance depends on the size of the magnetic flux inducers. Theses sizes were chosen to resonate the closed equivalent circuit at 51 MHz. The analysis predicts that the diameters of four 51 MHz-tanks are kept in the same size (134 cm) by adjusting the radius of the drift tubes of each tank in the range of 2~4 cm, and by adjusting sizes of the magnetic flux inducers. Predicted effective shunt-impedances are shown in Table 1 together with maximum peak powers. In this table, the reduction factor of 0.6 is included in the shunt impedances and the consumption powers. This factor is due to the surface roughness of conductor and the contact resistance.

B. Low Power Models

On the basis of the analysis described in (a), 1/2 scaled low power models for the tank-1 and tank-4 were constructed. Schematic drawing of the tank-4 model is shown in Fig.4.

The rf measurements are now in progress. In a preliminary result, the resonant frequency of 106 MHz (the design value is 102 MHz) was obtained for the tank-4 model. Figure 5 shows the field distribution of the tank-4 model measured by the bead perturbation method. Shunt impedance of the tank-4 estimated from this field measurement is about 230 MΩ/m for the practical use machine, which roughly agrees with that by the equivalent circuit analysis. The field distribution and the resonant frequency will be optimized by increasing the area of the magnetic flux inducer.

In these models, the end drift tubes were designed to be movable to the axial direction. In practical use machine, the end plate of the end drift tubes is slightly bent by vacuum pumping of the tanks. The effect of this bend on the rf characteristics of the cavity will be investigated.

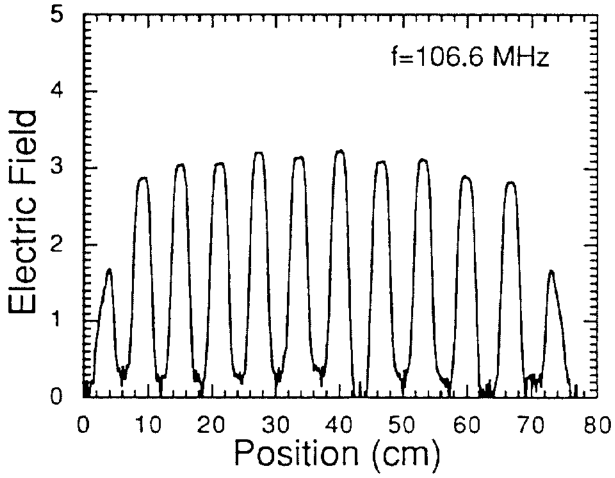

Fig.5 Measured field distribution of the tank-4 model.

V. SCHEDULE

The tests on the model cavities will be completed in summer 1993. Two of four acceleration tanks and all of four rf amplifiers for the practical use will be constructed in the fiscal year 1993. The remaining two tanks will be constructed together with two sets of the quadrupole triplets in the fiscal year 1994. First beam test is planned in the fiscal year 1995.

VI. ACKNOWLEDGEMENT

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