MODEL MEASUREMENT AND PRESENT STATUS OF INTERDIGITAL-H LINAC AT INS

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Abstract

In the radioactive-beam facility at INS, unstable nuclei with a charge-to-mass ratio greater than 1/10 are designed to be accelerated from 170 to 1046 keV/u by an interdigital-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 operating tank. Low-power cavity models were constructed and rf measurements were performed. A prototype model of the quadrupole triplet was constructed, and the field strength was measured. In this paper, measured results with the models are described together with a present status and a schedule.

Introduction

In the radioactive-beam facility at INS, unstable nuclei produced by bombarding a thick target with 40 MeV proton beam (~10 μA) from the existing SF cyclotron are ionized in ion sources, mass-analyzed by an Isotope Separator On Line (ISOL), and transported to the following accelerator complex.

The accelerator complex consists of a 25 MHz-SCRFQ (split coaxial RFQ), a 51MHz-IH (interdigital-H type) linac and a matching section between the SCRFQ and the IH linac[1,2]. Unstable nuclei with an energy of 2 keV/u from the ISOL are accelerated up to 172 keV/u by the SCRFQ. The SCRFQ was designed to accelerate beams with a charge-to-mass ratio (*q/A*) greater than 1/30 with a duty factor of 30 %. Beams with a *q/A* less than 1/10 are charge-exchanged by a carbon stripper placed after the SCRFQ. And they are accelerated up to about 1 MeV/u by the IH linac through two quadrupole doublets and a 25.5 MHz-rebuncher. The SCRFQ can accelerate the beam with a q/A greater than 1/16 at a duty factor of 100 %. Therefore, the IH linac is operated at c.w. mode for beams with a minimum *q/A*.

The IH linac has four axially short tanks designed in order to change the output energy continuously. The quadrupole triplets are placed between the tanks. Main parameters of the IH linac are listed in Table 1. Schematic view of the IH linac is shown in Fig. 1.

Model Measurement

To estimate a rough dimension of the IH linac, an equivalent circuit analysis was performed[3]. We can calculate a shunt impedance from the capacitance, inductance and surface resistance obtained per each cell. In this calculation, the reduced factor of 40 % is assumed to consider the effect due to end capacitances and the actual surface resistance. The shunt impedances for some IH linacs at other institutes are roughly reproduced by this factor[4]. The effective shunt impedances (Zeff) predicted for the tank-1 to tank-4 are listed in Table 2.

First, an rf measurement for the tank-4 was performed using a lower power model (1/2 scale). On the basis of the analysis described above, the tank diameter is chosen to be 1340 mm (at the size for the practical machine). Measured resonant frequency was 117.3 MHz for the design size (the design frequency is 102 MHz). The measured resonant frequency is explained within error of 2.5 % by an equivalent circuit analysis in which the end circuit is modified. The resonant frequency near design one was obtained by adjusting the size of the magnetic flux inducer and the drift tube diameter[3]. Measured field distribution is shown in Fig. 2. The deviation from the average of the gap voltage is ±1.9 %.

TABLE 1
Main Parameter of the 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 ~ 294	294 ~ 475	475 ~ 725	725~ 1053
velocity β (%)	1.91 ~2.51	2.51 ~ 3.19	3.19~ 3.94	3.94 ~ 4.75
synchronous phase (deg)	-25	-25	-25	-25
tank length (m)	0.68	0.90	1.16	1.53
tank diameter (m)	1.49	1.49	1.49	1.34
bore diameter (mm)	20	24	28	32
drift tube diameter (mm)	38	44	46	52
cell number	9	10	11	12
acceleration gradient (MV/m)	2.10	2.15	2.17	2.14

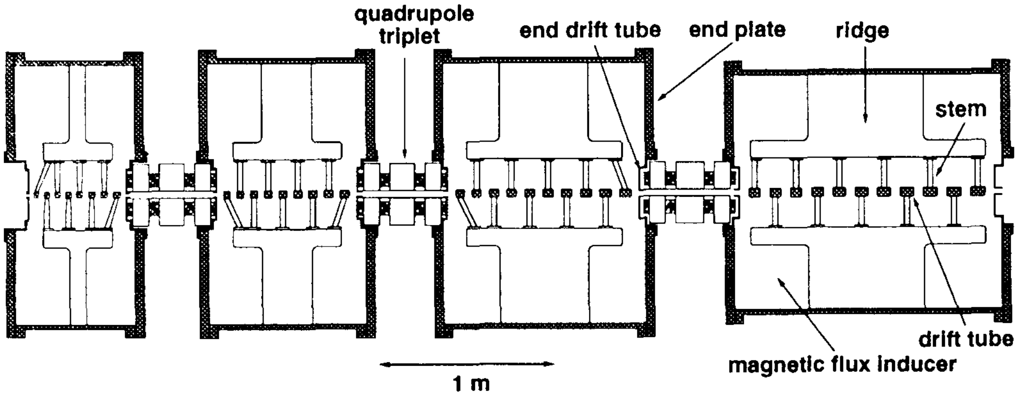

Fig. 1 Schematic drawing of the IH linac.

Zeff and power consumption estimated from the field measurement are written in Table 2. The difference between the model and practical machine on the surface roughness and rf contact are not included in this estimation.

For a 1/2 scale model of the tank-1 with the same diameter as the tank-4, the resonant frequency near the design frequency was obtained by adjusting the size of the magnetic flux inducer. But the measured shunt impedance was rather small compared with the predicted value. To obtain higher shunt impedance, we performed the following modification; To decrease the capacitance between the end plate and the faced ridge surface, the both end of ridges are cut, and the drift tubes at the both sides are supported by inclined stems. The end plates are moved outside without changing the position of the quadrupole triplet. Furthermore, the tank diameter is changed from 1.34 to 1.48 m (at the size of the practical machine) to reduce the resonant frequency. In the modified model, sizes of the ridges, stems and drift tubes were reduced instead of increasing the tank diameter, that is, the scale factor of the model was changed from 1/2 to 9/20 (the design frequency is from 102 MHz to 113.33 MHz). As a result, the frequency near the design one was obtained by adjusting the size of the magnetic flux inducer. The deviation from the average of the gap voltage is ±2.4 % (Fig. 2). The shunt impedance was improved by about twice, but it is still lower than the estimated value. The difference between the predicted and measured Zeff is explained as follows; The predicted one is obtained on the basis of data for the axially long enough IH linacs. The effect of the power consumption on the end plates is relatively larger than that of an axially long linac. But the power consumption expected for the practical machine is only 10 kW, which is accepted in our construction plan.

The rf measurements of the tank-2 and tank-3 were performed under the same scheme as for the tank-1. The measured field distributions are shown in Fig. 2. The expected Zeff and power consumption for the practical machines are listed in Table 2. The deviations from the average of the gap voltage for the tank-2 and tank-3 are ±4.0 and ±3.2 %, respectively. At present, the resonant frequency for the tank-3 is smaller than the design one. It will be tuned by adjusting the size of the magnetic flux inducer.

In our design, the gap voltage distribution was assumed to be flat to prepare the drift tube table. The beam simulation was performed to investigate the effect of the actual distribution on the beam motion. This simulation shows that the influence on the longitudinal acceptance and the output energy spread is very small.

TABLE 2
Effective Shunt Impedance and
Power Consumption for the Practical Machine

	Zeff (MΩ/m) (predicted)	Zeff(MΩ/m) (from model)	Power (kW)
tank-1	580	249	10
tank-2	400	224	20
tank-3	280	247	27
tank-4	200	180	47

TABLE 3
Required, Calculated and Measured B'L
for the Quadrupole Magnets

	B' L (T)	
	QS	QL
required value		
tank1-2	4.3	6.4
tank2-3	4.2	7.0
tank3-4	4.4	7.6
3-D calculation	4.9	7.4
measurement	4.8	7.3

Quadrupole Triplet

To obtain large transverse acceptance, the bore radius of the quadrupole magnets was chosen to be 20 mm. Strong field gradient (about 5 kG/cm at maximum) is required to focus the beam. Further, compact sizes are required to make the drift space as short as possible. Total axial length of the quadrupole triplet is limited to about 50 cm. Design of the quadrupole magnets was performed by the 2-dimensional code TRIM. The yoke has an octagonal shape. The coil has two channels for water cooling per pole. In our quadrupole triplet, adjacent magnets are closely placed. A prototype model of the quadrupole triplet was constructed in order to investigate the coupling effect between adjacent magnets. The measured B'L (the field gradient integrated along the axial direction) are listed in Table 3 together with the calculated results of the 3-dimensional code (ELF-MAGIC). In this measurement, three magnets were excited at maximum currents. Measured B'L satisfied the required one except for that of the middle magnet

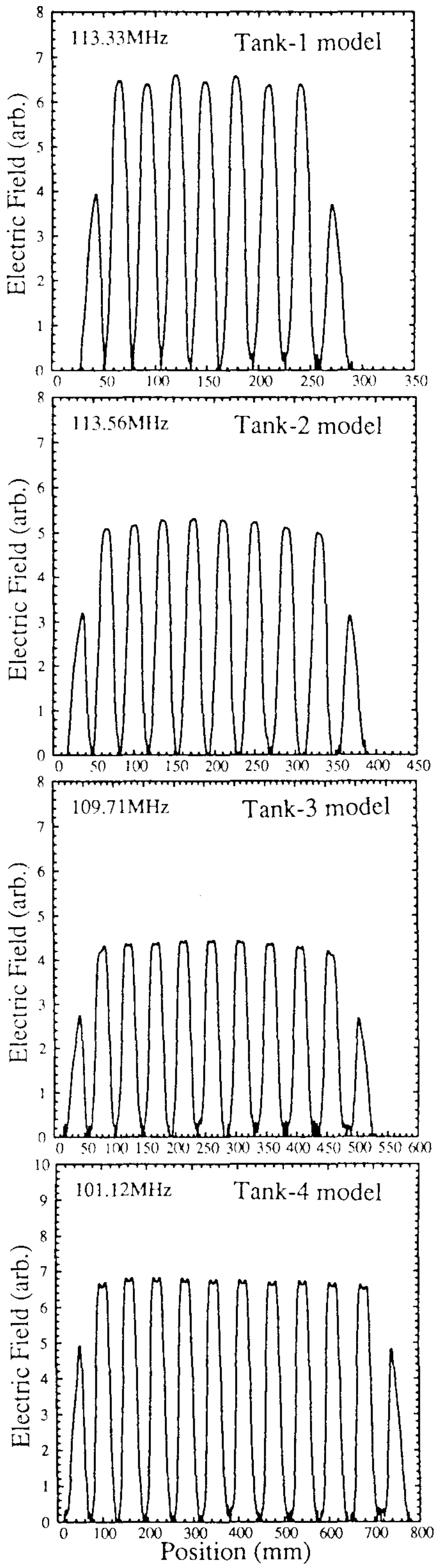

Fig. 2 Electric field distribution of the tank-1 ~4 models.

in the last triplet. This model will be used as a practical use one placed between the tank-1 and the tank-2. For the middle magnet in the last triplet, the axial pole length will be increased by 1 or 2 cm to attain the required strength. From the beam simulation, the effect of this change on the longitudinal beam motion is negligibly small.

Present Status and Schedule

The resonant frequency for the tank-4 is tuned by a capacitive tuner, an inductive piston tuner and four inductive tuners. The center frequency is adjusted in the range of ±100 kHz by the capacitive and the end inductive tuners. The frequency shift due to temperature change is automatically compensated by the inductive piston tuner within ±50 kHz. A cooling system for the tank-4 was designed on the basis of a three dimensional heat analysis. The tank-4 for practical use and its rf amplifier (50 kW c.w.) have been manufactured. The low level rf measurement will be started soon. The heat analysis for the tank-1~3 is now in progress. After fine frequency tuning using the tank-1~3 models, the three tanks for practical use and these rf amplifiers will be constructed together with two set of the quadrupole triplets in this fiscal year. The high power tests for the tank-1~4 will be done at the beginning of the fiscal year 1995. First beam test using the stable beam is planned at the end of the fiscal year 1995.

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