Construction of an 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 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 last operating tank. On the basis of an equivalent circuit analysis, low power models were constructed. Resonant frequency close to the design value and flat gap voltage distribution were obtained for the tank-4 model. On the basis of the model measurement, the tank-4 for the practical use was designed and constructed. In this paper, a present status on the IH linac is described together with a brief summary of the studies done so far.

1 INTRODUCTION

Construction of the radioactive-beam facility, which is a prototype of the exotic nuclei arena (E-arena) proposed in the Japanese Hadron Project(JHP)[1,2], has been started in 1992 at INS. The prototype facility is constructed in the existing building at the present INS campus. The accelerator complex in the prototype facility consists of an SCRFQ (split coaxial RFQ), an IH (interdigital-H type) linac and a matching section between the SCRFQ and the IH linac[3-6]. 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 a duty factor of 100 % to accelerate beams with a q/A greater than 1/10.

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 an acceleration 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 parameters of the designed IH linac are listed in Table 1.

The resonant frequency of the IH linac is chosen to be twice as high as that of the SCRFQ. The length of the drift spaces is taken to be 47.5 cm to keep the phase spread small. In a simulation, longitudinal acceptance of 200π keV/u•deg is obtained (at the entrance of tank-1), which is nearly three times as large as the predicted beam emittance from the SCRFQ. The SCRFQ accepts beams with the transverse normalized emittance of 0.6π mm•mrad at maximum. An acceptance larger than this value is required because of an emittance growth at the charge stripper[6]. The acceptance of about 2.4π mm•mrad (transmission 97%) is achieved by setting the bore radius of quadrupole magnets at 20 mm.

2 DESIGN OF TANK-4

To estimate a rough dimension of the tank-4, an equivalent circuit analysis was performed. The computer code SUPERFISH (static version) was used to estimate the

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 ~ 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)	0.59	0.84	1.15	1.53
cell number	9	10	11	12
acceleration gradient (MV/m)	2.10	2.15	2.17	2.14

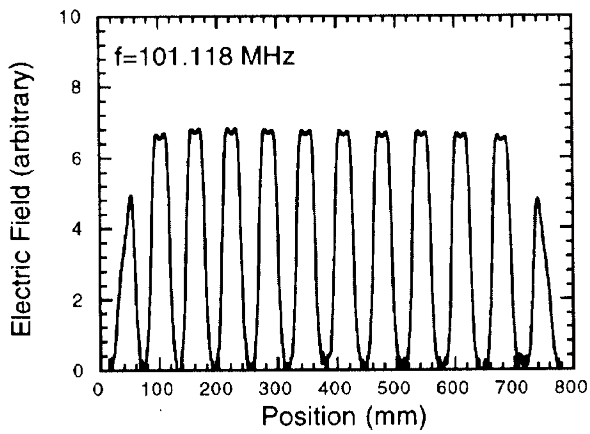

Fig. 1 Measured field distribution in the tank-4 model.

capacitances. The tank inductance was obtained assuming axial magnetic flux density is constant in the cross section of the tank. Stem inductance was obtained as rf current flows on the cylinder surface[7]. Series inductance was obtained assuming the axial electric current flows on the ridge surface facing each other[8]. In this design, the stem diameter (30 mm) and the distance between facing ridge surfaces (200 mm) were fixed. The tank diameter was determined to be 1340 mm in diameter from this prediction of this equivalent circuit analysis.

On the basis of the analysis described above, 1/2 scale low power models for the tank-4 were constructed. Measured resonant frequency was 117.3 MHz for the design size (the design frequency is 102 MHz). Resonance frequency of 101.969 MHz was obtained by increasing the size of the magnetic flux inducer. In this measurement, a deviation of the gap voltages excluding the end cells was attained to be ±4 %. Measured shunt impedance is about 160 MΩ/m. The gap voltage distribution has a small peak around the center of cells. In order to obtain flatter voltage distribution and the higher shunt impedance, we tried to use thinner drift tubes. In the thinner drift tube, bore radius and axial length are same as these of the old design. The thickness and the curvature radius at outer corner of the tubes were changed from 14 mm and 4 mm to 10 mm and 8 mm (for size of practical machine), respectively. From the calculation of SUPERFISH assuming axial symmetry of the electric field, the capacitance between drift tubes decreases by 17 %, and Kilpatrik-factor decreases from 1.76 to 1.58. The model measurement using a new drift tubes was performed. Tuning of the resonant frequency was done by adjusting the size of the magnetic flux inducer. As a result, the resonant frequency near the design value was obtained. Figure 1 shows the field distribution measured by a bead perturbation method. Obtained deviation from the average of the gap voltage was decreased to ±1.9 %. Measured shunt impedance is 174 MΩ/m. Estimated effective shunt impedance and power consumption in the cavity for practical use are 180 MΩ/m and 47 kW, respectively. The difference between the model and practical machine on the surface roughness and rf contact are not included in this estimation. Designed tank-4 for practical use is shown in Fig. 2.

In the practical use machine, a plate of the end drift tube (in which the quadrupole magnet is installed) is slightly distorted by vacuum pumping of the tank. This distortion is estimated to be 0.3 mm from a mechanical calculation. The effect of the distortion on the rf frequency shift was measured by moving the end drift tube in the model to axial direction. The measurement shows the frequency shift for 0.3 mm distortion is 28 kHz (0.055 % of 51 MHz), which is compensated by using tuners as described next.

Frequency tuners in the tank-4 consist of a capacitive tuner (C-tuner), an inductive piston tuner (L-tuner) and four inductive tuners (end L-tuners). The C-tuner is a disk of 190 mm in diameter. Figure 3 shows measured frequency shift and Q-value with distance between the C-tuner and the ridge surface. The C-tuner is moved in the range in which Q-value does not change. In this range, the frequency change is 100 kHz for 51 MHz in the stroke of 200 mm. The four end inductive tuners (end L-tuners) are placed at top and bottom of the tank as shown in Fig. 2. We measured the shunt impedance by changing the position of the end L-tuner in the model(Fig. 4). The distance between the end L-tuner and the end plate is taken to 325 mm where the shunt impedance is

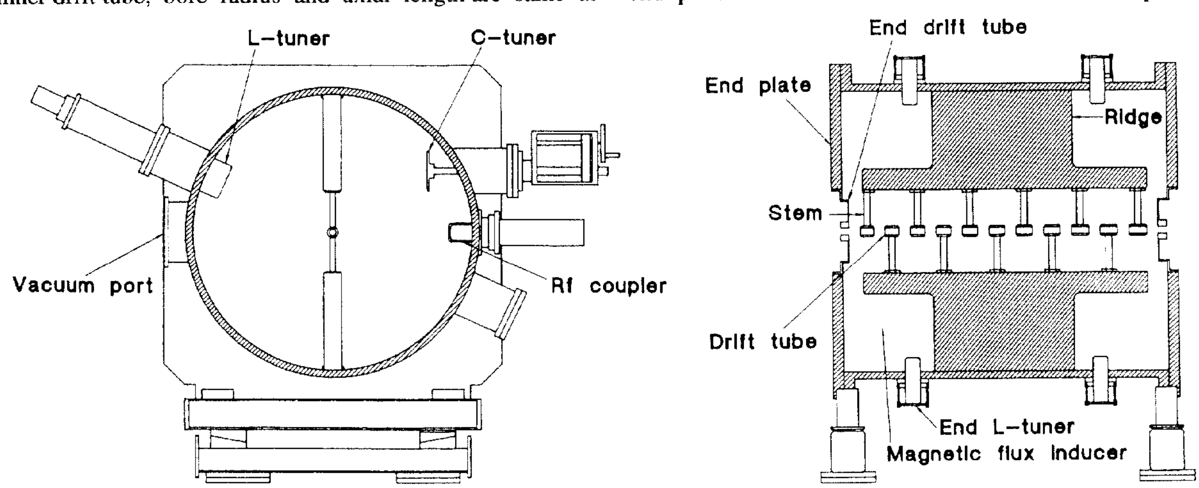

Fig. 2 View of designed tank-4.

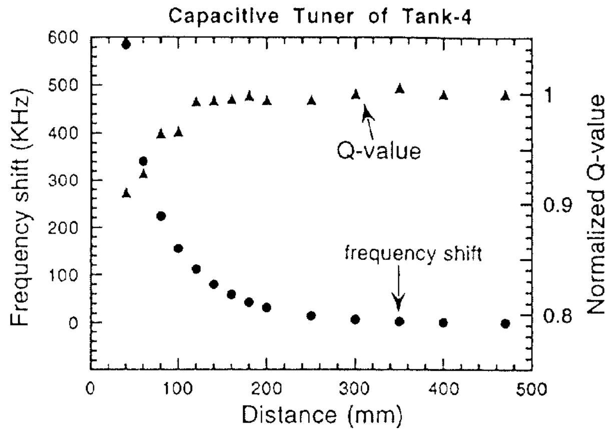

Fig. 3 Measured frequency shift and Q-value as a function of distance between the C-tuner and the ridge surface (the distance and frequency are for the practical machine).

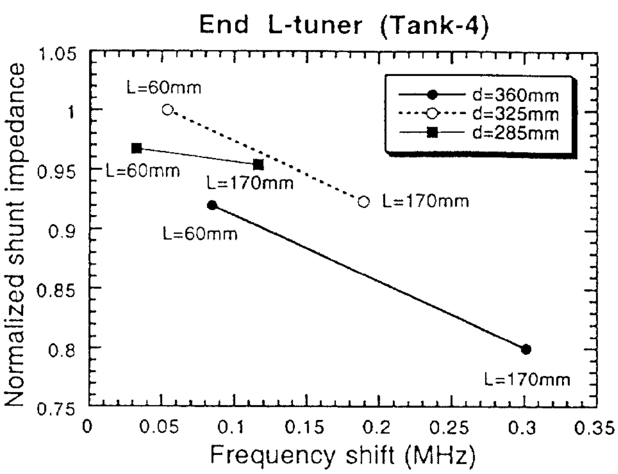

Fig. 4 Effect of the end L-tuners. In the figure, D is distance between the tuners and the end plate, and L is length of the tuners. Diameter of is 70 mm (the size and frequency are for the practical machine).

optimum. An inductive piston tuner placed at the tank wall has diameter of 200 mm and stroke of 200 mm. The frequency shift due to temperature change is automatically compensated by this tuner within ±50 kHz.

Total power consumption on the tank wall, ridges and stems is taken to be 50 kW on the basis of the result of the model measurement. Power consumption on the tank wall, ridges and stems is 18.3, 15.6 and 16.1 kW, respectively. Power consumption on the end plates is taken to be 17 kW, which is the difference between power consumption obtained from the model measurement and calculated by assuming infinitely long tank to axial direction. On the basis of this estimation, three dimensional heat analysis was performed to know a maximum temperature increase and an expansion. In this analysis, water flow rate was determined not to exceed temperature increase of 1.5°C for input temperature of 30°C. Maximum temperature increase at the tank wall and ridges-stems is 20 and 15°C, respectively. The expansion of the tank to radial direction due to the temperature increase is 73 μm. Frequency shift due to this expansion is estimated to be 10 kHz, which is compensated by the tuners.

3 PRESENT STATUS AND SCHEDULE

The tank-4 for the practical use and its rf amplifier (50 kW c.w.) were constructed. A prototype model of the quadrupole triplet was constructed, and a field measurement was performed. Preliminary result is shown in ref. [9] . Model measurement for the remaining three tanks is now in progress. In preliminary result, resonant frequency near design one and satisfactory shunt impedance were obtained for the tank-1 and tank-2 model. Construction of the remaining three tanks for practical use and their rf amplifiers is scheduled together with two sets of the quadrupole triplets this fiscal year. First beam test is planned in the fiscal year 1995.

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