LINAC COMPLEX IN THE JAERI-KEK JOINT RNB FACILITY

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Abstract

Construction of the JAERI-KEK joint RNB facility has started from 2001 at JAERI-Tokai tandem site. In the first stage, the facility comprises a tandem accelerator, an isotope-separator on line and a linac complex. The radioactive nuclear beams (RNBs) are produced by a 36-MeV 3-μA proton beam from tandem accelerator. The linac complex comprises a 26-MHz split coaxial RFQ and a 52-MHz interdigital-H (IH) linac. The beam energy is available in the range of 0.14 to 1.09 MeV/u. In the second stage, the RFQ/IH linac is connected to the JAERI superconducting tandem booster linac by adding a 2-MeV/u linac between them. The extended linac complex can provide the maximum beam energies of 5 Mev/u for q/A=1/7 ions and 8 MeV/u for q/A=1/4 ions.

1 INTRODUCTION

A radioactive-nuclear-beam (RNB) acceleration facility based on an isotope-separator on line (ISOL) method was constructed at KEK-Tanashi from 1992 to 1995, which was a prototype for the exotic nuclei arena of Japanese Hadron Facility. The main purpose of the prototype was to carry forward R&D of the ISOL and linacs for RNBs as well as the studies on nuclear astrophysics, etc. In the KEK RNB facility, a linac complex composed of a 25.5-MHz split-coaxial RFQ (SCRFQ) with modulated vanes and a 51-MHz interdigital-H (IH) linac was employed as a post accelerator.

The KEK RNB facility was closed in 1999 because of move of KEK-Tanashi branch to KEK-Tsukuba. However, fortunately, construction of the JAERI-KEK joint RNB facility (see Fig. 1), which is also based on the ISOL method, has started from 2001 at JAERI-Tokai tandem accelerator site. This project has following merits: 1) The RNBs with the energy above Coulomb barrier are realized at low construction cost, by utilizing two existing linacs, that is, the KEK linac and the JAERI superconducting linac (SC-linac). 2) Uranium target is available for RNB production in the JAERI-Tokai site.

In the first stage, the RFQ/IH linac is reconstructed, and the RNBs with the energy of 0.14 to 1.09 MeV/u are provided. In the second stage, the beam from the RFQ/IH linac is accelerated by an IH2 linac up to 2-MeV/u, and further accelerated by the SC linac up to the energy above Coulomb barrier. For achieving this scheme, the IH2 linac and two rebunchers (RB2 and RB3) should be newly built, and the RFQ/IH linac modified to increase the resonant frequency by about 2%.

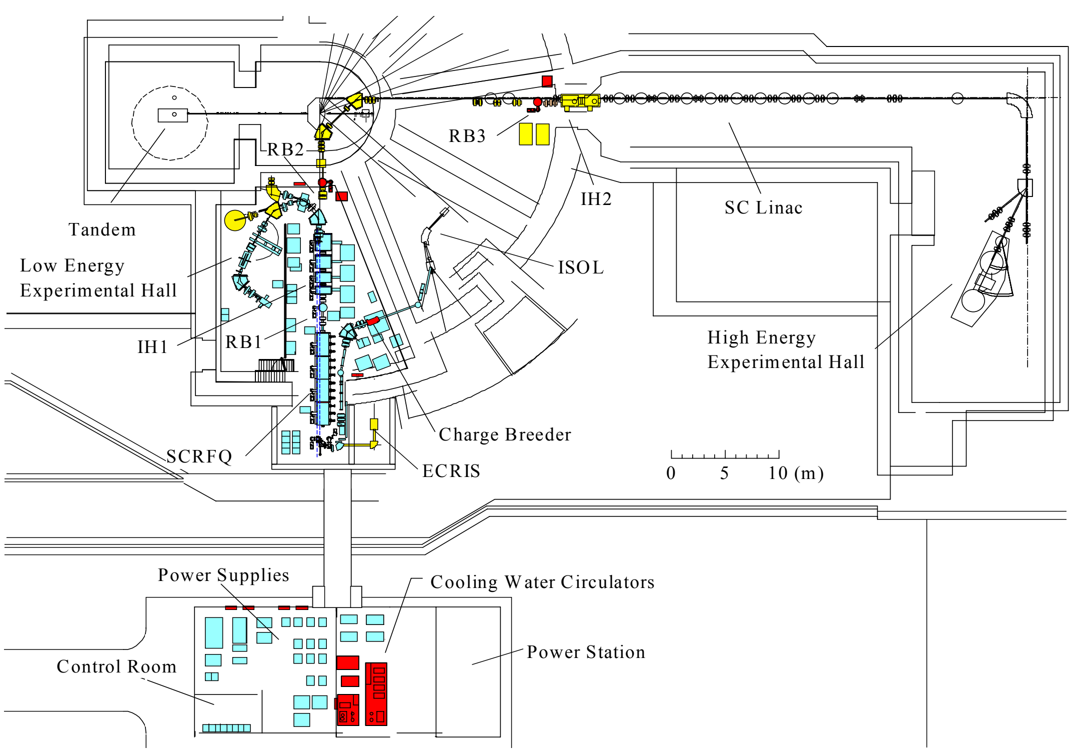

Figure 1: Layout of the JAERI-KEK RNB facility.

2 OUTLINE OF FACILITY

Radioactive nuclei are produced by bombarding a thick target with a 36-MeV 3-µA proton beam from the tandem accelerator. A charge state of radioactive ions from ISOL are exchanged to higher charge states by using a charge breeding electron cyclotron resonance ion source (CB-ECRIS). Therefore, it becomes possible that SCRFQ accelerates radioactive ions with a mass number larger than 28. On the other hand, high current stable nuclear beams are produced by a local ECRIS. The beams from RFQ/IH linac are switched into two courses. One leads to a low energy experimental hall for studies on nuclear astrophysics, etc. Other joins the beam line of tandem to SC linac. The 1.09-MeV/u beams are further accelerated by the IH2 and SC linacs, and transported to a high energy experimental hall. Two rebunchers (RB2 and RB3) are located between the IH and IH2 linacs.

3 KEK SCRFQ/IH LINAC

3.1 Features and Performances

The SCRFQ accelerates ions with a charge-to-mass ratio (q/A) greater than 1/30 from 2 to 172 keV/u. The machine size is very compact compared with the conventional four-vane RFQ with the same resonant frequency. The beam transmission efficiency is higher than 90% even when the q/A=1/28 ions are accelerated from very low energy of 2 keV/u. On the other hand, the IH linac accelerates ions with a q/A greater than 1/10 up to 1.05 MeV/u. The IH linac is a separated function drift-tube linac, which comprises four tanks and three magnetic-quadrupole triplets between tanks. Output beam energy is continuously varied by adjusting independently the phase and amplitude of the rf field in each tank.

The acceleration performances were verified in the KEK RNB facility [1]. The achieved performances were as follows: 1) the transmission of the RFQ was higher than 90% (see Fig. 2) and that of the IH was nearly 100%, 2) the RFQ accelerated ions with a q/A from 1/2 to 1/28, 3) the IH was able to continuously vary the output energy in the range from 0.14 to 1.05 MeV/u (see Fig. 3), and 4) the measured 2-rms 90% energy spreads were less than 2.4%.

3.2 Modification of Cavities

The SCRFQ and IH linacs have resonant frequencies of 25.5 and 51 MHz, respectively, although the JAERI SC linac a resonant frequency of 129.8 MHz. We have to change frequency of the RFQ from 25.5 to 25.96 MHz and that of IH from 51 to 51.92 MHz. The resonant frequency of the RFQ is tuned by changing locally inter-electrode capacitance and stem (used for supporting the electrodes) inductance. Values of the capacitance and inductance to be changed are well estimated by using an equivalent circuit analysis. Even if the frequency changes, the accelerating performance of the SCRFQ does not change except that the beam energy changes from 172 to 178 keV/u. The resonant frequency of the IH linac is tuned by increasing the gap lengths between drift-tubes, that is, by decreasing the capacitance. All drift-tubes are replaced to the modified ones. The gap lengths are determined by model tests after rough estimations by MAFIA calculations.

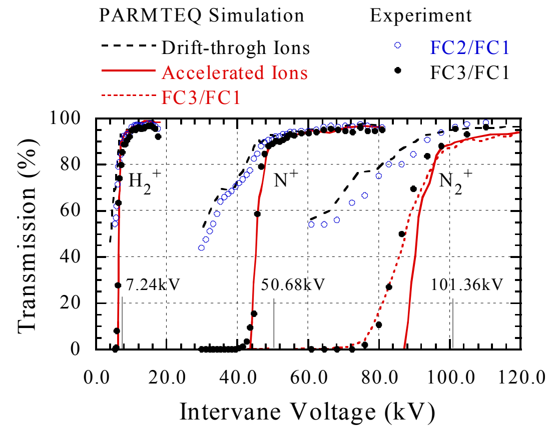

Figure 2: Beam transmission of the SCRFQ.

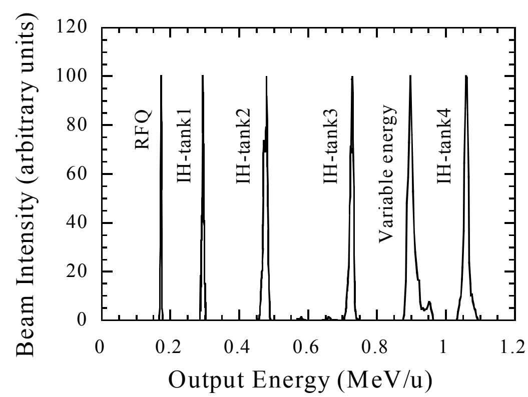

Figure 3: Beam energy spectra under the different operation modes.

4 JAERI SC-LINAC

4.1 Outline

SC linac [2] comprises 10 cryostats and 9 magnetic-quadrupole doublets set between cryostats. Four super-conducting cavities made of niobium are installed in each cryostat. The cavities are 129.8-MHz two-gap $\lambda/4$ resonators. Optimum ion velocity is 10% of light velocity for all cavities. This linac has large velocity acceptance, since the number of accelerating gap per cavity is only two and rf phase of each cavity can be independently adjusted.

4.2 Relation between Input and output energies

When q/A is the charge to mass ratio, V the accelerating voltage per cavity, $T(\beta)$ the transit time factor for ions with velocity β and ϕ the average accelerating phase, the energy gain per cavity is expressed as follows:

Table 1: Main parameters of linacs in the RNB facility

SCRFQ/IH LINAC	RFQ	IH
Frequency (f)	25.96	51.92 MHz
Total length	8.6	5.6 m
Diameter	0.9	1.49 for tanks 1-3 m 1.34 for tank 4 m
Synchronous phase (ϕ)	-30	-25 deg.
Charge-to-mass ratio (q/A)	≥1/28	≥1/10
Input energy (T_{in})	2.1	178 keV/u
Output energy (T_{out})	0.178	0.14-1.09 MeV/u
Normalized acceptance (A_n)	0.86π	1.7π mm·mrad
Duty factor	30	100 %
Repetition rate	20-1000 Hz	
IH2 LINAC	**Tank 1**	**Tank 2**
Frequency (f)	129.8 MHz	
Tank length	1.15	1.35 m
Synchronous phase (ϕ)	-25 deg.	
Charge-to-mass ratio (q/A)	≥1/7	
Normalized acceptance	1.4π mm·mrad	
Input energy (T_{in})	1.05	1.54 MeV/u
Output energy (T_{out})	1.54	2.03 MeV/u
Gap voltage (V_g)	250 kV	
Duty factor	100 %	
SC-LINAC		
Frequency (f)	129.8 MHz	
Number of cavities	40	
Cavity	λ/4 resonator	
Gap voltage (V_g)	0.375 MV	
Optimum ion velocity (β_0)	0.10	
Synchronous phase (ϕ)	-25 deg.	
Input energy (T_{in})	2 MeV/u	
Output energy (T_{out})	5 for q/A=1/7 MeV/u 8 for q/A=1/4	
Normalized acceptance	1.4π mm·mrad	
Duty factor	100 %	

$$\Delta E = \left(\frac{q}{A}\right) \cdot V \cdot T(\beta)\cos\phi \tag{1}$$

The transit time factor for two-gap cavity is approximately given by a following equation:

$$T(\beta) = \frac{2}{\pi}\frac{\beta}{\beta_0}\left[\cos\left(\frac{\pi}{4}\frac{\beta_0}{\beta}\right) - \cos\left(\frac{3\pi}{4}\frac{\beta_0}{\beta}\right)\right] \tag{2}$$

where β_0 is the optimum ion velocity. The relations between input and output energies were calculated for the q/A=1/4 and 1/7 cases under the condition that V=0.75 MV and $\phi = -25$ degrees. The results [3] are shown in Fig 4. The Figure shows that the SC linac can accelerate ions with the injection energy higher than 1.2 MeV/u. When the injection energy is 2 MeV/u, the maximum beam energy is 5 Mev/u for q/A=1/7 ions and 8 MeV/u for q/A=1/4 ions.

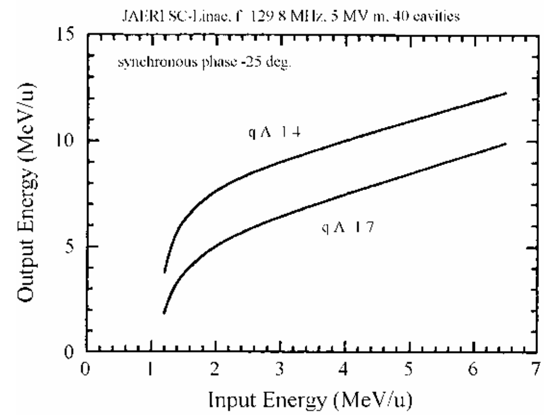

Figure 4: Relation between input and output energies of SC linac.

5 IH2 LINAC

Output beam energy of the RFQ/IH linac is too lower to inject directly to the SC linac. Therefore, an IH2 linac has been designed as a booster linac set between RFQ/IH linac and SC linac. From Fig. 4, output energy must be higher than 1.2 MeV/u, but it must be kept down to reduce the construction cost of the IH2 linac. We have decided by compromise that the output energy is 2 MeV/u. The IH2 linac accelerates ions with a q/A greater than 1/7 from 1.05 to 2 MeV/u. The resonant frequency is 129.8 MHz. Basic structure of the cavity resonator is similar to that of the KEK IH linac. Beam focusing magnets are not installed in the drift-tube for increasing the shunt impedance. Beam focusing is realized by setting quadrupole magnets before and behind the cavity tanks.

6 SUMMARY

Modification of the RFQ/IH linac and construction of the IH2 linac are required to connect the RFQ/IH linac to the SC linac. The cavity modifications to change the frequencies are performed in 2002. Main parameters of the linacs are listed in Table 1. Construction and extension of the RNB buildings are completed by March of 2003. After completion of the buildings, the RFQ/IH linac is installed in an RNB building. Beam commissioning on the first stage will be started in spring of 2004.

7 REFERENCES

[1] S. Arai et al., “Beam Test Results of the INS RFQ/IH Linac”, LINAC’96, Geneva, Switzerland, 1996, p. 575.
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[3] M. Tomizawa, KEK Report 99-6, 1999.