LINAC COMPLEX FOR RI BEAMS IN JAERI-KEK JOINT FACILITY

M. Tomizawa, S. Arai, Y. Arakaki, M. Okada, K. Niki and Y. Takeda,
High Energy Accelerator Reseach Organization (KEK),
1-1 Oho,Tsukuba-shi, Ibaraki 305-0801, Japan
S. Takeuchi
Japan Atomic Energy Research Institute(JAERI),
2-4 Shirakata-Shirane, Tokai-mura, Naka-gun,Ibaraki 319-11, Japan

Abstract

Construction of JAERI-KEK joint facility for RI beams based on the ISOL method has started from 2001at the tandem cite at JAERI-Tokai. Primary protons are accelerated by the existing tandem accelerator, and produced RI beams are accelerated up to 1 MeV/u by linacs which had been operated at KEK-Tanashi till 1999. They can be connected to the existing superconducting heavy ion linac together with an additional 2-MeV/u IH linac. This extension provides RI beams with higher energies above the Coulomb barrier.

1 INTRODUCTION

The RI beam facility based on the ISOL method had been constructed at KEK-Tanashi. Primary accelerator was a SF cyclotron with K=67. The linacs to accelerate RI beams (RIB) comprises the 25.5-MHz split coaxial RFQ(SCRFQ) and 51-MHz IH linac (IH1). Obtained main performance of the linacs are followed; (1)Beam transmission through the whole linacs was 90% , which includes the bunching efficiency of the SCRFQ. (2) The continuous energy variability was confirmed by tuning the rf voltage and its phase of four independent IH tanks. We also succeeded to accelerate RIB by the linacs for the first time in the world. This facility was closed in 1999 so as to move to KEK-Tsukuba.

A plan to utilize these linacs in the tandem facility with a superconducting booster linac at JAERI-Tokai has been approved, and construction of the facility to utilize 1-MeV/u RI beam based on the ISOL method has started from 2001 for three years. We mainly report the linac complex at this facility.

2 KEK AND JAERI HEAVY ION LINACS

2.1 KEK Linacs

The 25.5-MHz split coaxial RFQ (SCRFQ) accelerates ions with q/A greater than 1/30 from 2 to 172 keV/u. The duty factor is 30% for ions with q/A=1/30. The cavity, 0.9 m in inner diameter and 8.6 m in length, comprises four unit cavities, and each of which is composed of three modules (multi-module structure).

The 51-MHz IH linac (IH1) accelerates ions with q/A greater than 1/10 from 172 keV/u to 1 MeV/u. The IH1 has four independent tanks. A rebuncher (RB1) placed between the SCRFQ and the IH1 is a 25.5 MHz-double coaxial quarter wave resonator with six gaps.

2.2 JAERI Superconducting Linac

The superconducting linac has been utilized as an energy booster for heavy ions from the tandem accelerator. This linac comprises ten cryostats and inter-cryostat quadrupole doublets. Four 129.8 MHz-niobium quater wave resonators are installed in a cryostat. The optimum ion velocity β is designed to be 10% for all cavities.

3 CONNECTION OF KEK-LINACS WITH JAERI-SCL

3.1 Resonant Frequency

The beam from the KEK linac complex has 25.5-MHz bunch structure determined by the renonant frequency of the SCRFQ. The IH1 has double frequecy, 51 MHz. The beam bunch from the SCRFQ is accelerated by the IH1 every two rf cycle as shown in Figure 1. On the other hand, the resonant frequency of the SCL is 129.8 MHz. The beam bunch from the KEK linac complex can be ac-

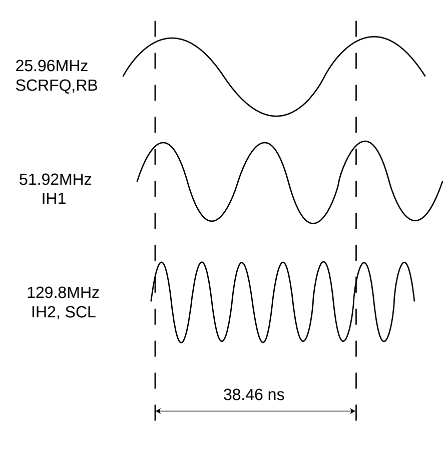

Figure 1 Time structure of beam bunch and rf fields.

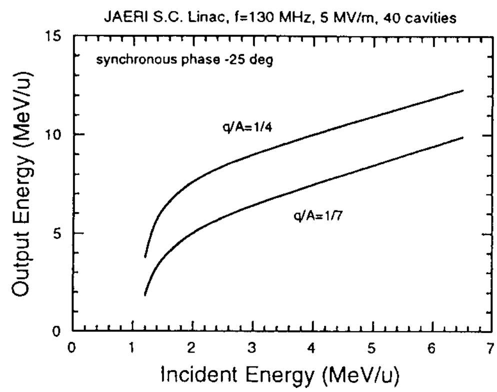

Figure 2 Maximum energy accelerated by the SCL as a functon of incidnt energy.

celerated by the SCL, if the frequencies of the SCRFQ and the IH1 can be increased by about 2%, that is, 25.96 and 51.92 MHz, respectively.

We have studied method to change the frequencies of the SCRFQ, the RB1 and the IH1.The SCRFQ cavity has L-shape plates to change capacitance between stem flange and backplates of vanes, and plates for closing the stem-flange windows to change inductance. Due to an equivalent circuit analysis, the frequency can be changed from 25.5 MHz to 25.96 MHz by adjusting the size of these plates so as to keep a flat intervane voltage distribution. The frequency change of the IH1 is performed by increasing the gap lengths between drift tubes in order to decrease the capacitance. All drift tubes are replaced to new ones. The gap lengths are determined by model tests after rough estimations by MAFIA calculations. A method to change the frequency of the RB1 is same as that of the IH1. The final gap length is determined from the SUPERFISH and MAFIA calculations.

3.2 Injection Energy Matching to SCL

The SCL has large velocity acceptance, since the accelerating gap number of a cavity is only two and the rf phase of each cavity can be independently tuned. Transit time factor of the two-gap cavity is written as

$$T(\beta) = \frac{2}{\pi}\frac{\beta}{\beta_0}\left[\cos\left(\frac{\pi}{4}\frac{\beta_0}{\beta}\right) - \cos\left(\frac{3\pi}{4}\frac{\beta_0}{\beta}\right)\right] \qquad (1)$$

where, β is beam velocity divided by the light velocity, and β_0 is designed one of the cavity. Then energy gain per a cavity is expressed as

$$\Delta E = \left({}^{q}\!/\!{}_{A} \right) \cdot V \cdot T(\beta) \cdot \cos\phi \qquad (2)$$

where, V is voltage generated per a cavity and ϕ is synchronous phase. Figure 1 shows acceleration energy as a function of incident energy calculated from Eq. (1) for V=750 kV corresponding to field gradient of 5 MV/m, ϕ = -25° and 40 cavites. Good acceleration efficiency is obtained for incident energy of above 2 MeV/u. Therefore a linac to accelerate 1 MeV/u - ions to 2 MeV/u is required to inject to the SCL. We choose an IH linac (IH2) as this accelerator.

3.3 SCL Acceptance

Present beam optics of the SCL is optimized so as to accelerate the tandem beam with small emittance. This optics is not enough to accept the beam from the KEK linacs complex. In order to increase the acceptance, a periodic structure of doublet FODO will be adopted just by changing polarities of quadupole currents. And beam collimators placed in front of the cryostat will be removed. It would not cause a serious damage for the cavities, since RI beam intensity is very low. From the tracking simulation, the transverse acceptance is increased to1.4π mm•mrad at normalized value.

4 OUTLINE OF JOINT FACILITY

Figure 3 shows a layout of the JAERI/KEK RNB facility. In this facility, primary protons or various heavy ions to produce RIB are accelerated by an 18 MV tandem accelerator. For example, in case of protons, 36 MeV, 3 μA beam is available. In this facility, fission induced heavy neutron-rich RIB can be produced by using UC target as well as light RIB. The charge state of RIB with single charge state can be increased by charge borrding 18 GHz-ECRIS, and accelerated by the SCRFQ and the IH1 up to 1MeV/u. A beam transport line between the IH1 and IH2 comprises two rebuchers(RB2-3) and 90° bending section. Newly constructed two rebunchers are double coaxial quater wave resonators with 4 gaps. Their frequency is chosen to be 25.96 MHz to reduce longitudinal aberation due to nonlinearity of accelerating field. A newly constructed IH linacs (IH2) is placed just before the SCL. The IH2 has frequency of 129.8 MHz same as that of the SCL , and accelerates ions with *q/A* of 1/ 7 from 1 to 2 MeV/u. Number of tanks is two, a quadrupole triplet is placed between two tanks. The 2 MeV/u beams from the IH2 are injected into the SCL and can be accelerated up to energies above the Coulomb barrier. Main parameters of the linac complex is listed in Table 1.

5 SCHEDULE

The frequency modification of the SCRFQ, RB1 and the IH1 will be done 2001 to 2002. By the end of 2003, installations of the whole system will be finished. The RIB up to 1 MeV/u will be available from 2004. The first RIB acceleration by the SCL will be planed in 2006.

Table 1 Main parameters of linacs in JAERI/KEK joint facility for RIB.

SCRFQ(frequency changed)	
frequency	25.96 MHz
input energy	2.1 keV/u
output energy	178.4 keV/u
tank length	8.6 m
min. *q/A*	1/29
max. vane voltage	112.5 kV
n.emittance	0.61π mm•mrad
beam transmission	91.4%
duty factor	30% for *q/A*=1/29
RB1(frequency changed)	
frequency	25.96 MHz
number of gaps	6
min. *q/A*	1/10
duty factor	100%
IH1(frequency changed)	
frequency	51.92 MHz
number of tanks	4
focusing	inter-tank Q-triplet
synchronous phase	-25°
input energy	0.176 MeV/u
output energy	1.09 MeV/u
total length	5.8 m
min. *q/A*	1/10
n.acceptance	1.7π mm•rad
duty factor	100%
RB2 and RB3 (newly constructed)	
frequency	25.96 MHz
number of gaps	4
min. *q/A*	1/7
duty factor	100%
IH2(newly constructed)	
frequency	129.8 MHz
number of tanks	2
focusing	inter-tank Q-triplet
synchronous phase	-25°
input energy	1 MeV/u
output energy	2 MeV/u
total length	3.1 m
min. *q/A*	1/7
n.acceptance	1.4π mm•rad
duty factor	100%
SCL(no modification for cavities)	
frequency	129.8 MHz
number of cryostats	10
number of cavities	40
focusing	inter-cryostat Q-doublet(FODO)
synchronous phase	-25°
input energy	2 MeV/u
output energy	6 MeV/u (*q/A*=1/7) 9 MeV/u (*q/A*=1/4)
typical field gradient	~5 MV/m
n.acceptance	1.4π mm•rad
duty factor	100%

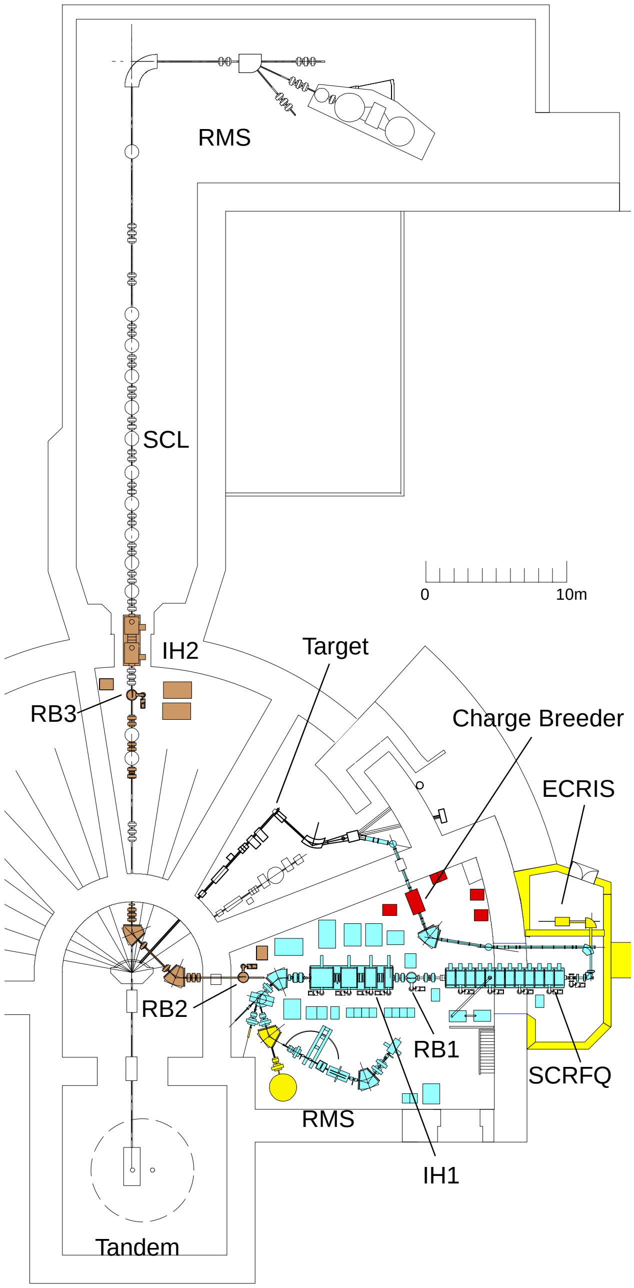

Figure 3 Layout of JAERI/KEK RIB Facility.

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