

# LINAC COMPLEX OF THE RADIOACTIVE BEAM FACILITY AT KEK-TANASHI

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## Abstract

The heavy ion linac complex of the ISOL based radioactive beam facility at KEK-Tanashi comprises of a split-coaxial RFQ, an interdigital-H linac and a transport line between them. Beam tests using stable beam have been done in order to investigate the performance of the linacs. The beam-transmission efficiency through the whole linacs exceeds 90%. First acceleration test of a radioactive nuclear beam was performed. We succeeded to accelerate  $^{19}\text{Ne}^{2+}$  ions to 0.72 MeV/u by the heavy-ion linacs.

## 1 INTRODUCTION

The construction of an ISOL-based radioactive nuclear beam facility at INS started in 1992 and completed in 1996. Radioactive nuclei, produced by bombarding a thick target with protons or light ions from an SF cyclotron, are ionized in an ion source, mass-analyzed by an isotope separator on line (ISOL), and transported to a heavy ion linac complex through a 60 m long beam line. The linac complex comprises a 25.5 MHz split coaxial RFQ (SCRFAQ) and a 51 MHz interdigital-H (IH) linac, and accelerates heavy ions up to 1 MeV/u.

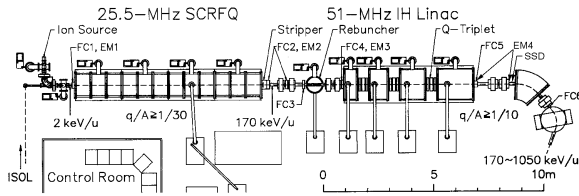


Figure 1: Layout of the linac complex.

This facility is a prototype for the exotic nuclei arena (E-arena) of the Japanese Hadron Facility (JHF), in which 3 GeV, 10  $\mu\text{A}$  protons is used as a primary beam, and a radioactive nuclear beam is accelerated up to 6.5 MeV/u by an extension of the IH linac [1]. The main purpose of the prototype facility is to study various technical problems for the E-arena in the JHF and to perform pioneering works with respect to nuclear astrophysics. A summary of the outline and the present status of the linac complex are reported in this paper.

## 2 OUTLINE OF THE LINAC COMPLEX

### 2.1 RFQ

A split coaxial RFQ (SCRFAQ) has been developed to accelerate heavy ions with a small  $q/A$  at INS [2]. Design parameters of the SCRFAQ are summarized in Table 1. The

SCRFAQ accelerates ions with a charge-mass ratio ( $q/A$ ) greater than  $1/30$  from 2 to 172 keV/u. The resonant frequency is chosen to be 25.5 MHz to accelerate the ions with  $q/A \geq 1/60$  considering future extension. The duty factor can be 30% for ions with  $q/A=1/30$  and 100% for  $q/A \geq 1/16$ . The cavity, 0.9 m in inner diameter and 8.6 m in length, comprises four unit cavities, and each of which is composed by three modules. The intervane voltage was obtained by measuring the endpoint energy of x-rays generated from the cavity. As a result, the resonance resistance ( $=V^2/2P$ ) was  $24.55 \pm 0.44 \text{ k}\Omega$ .

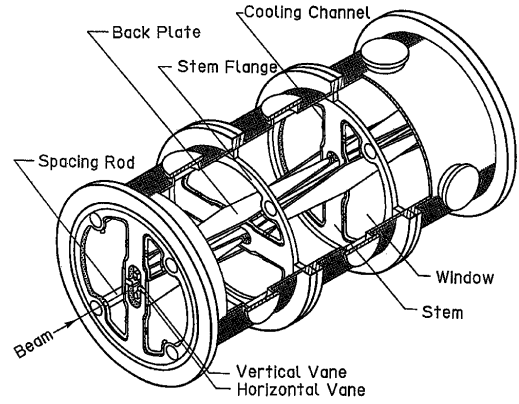


Figure 2: SCRFAQ view.

### 2.2 Transport Line between RFQ and Drift Tube Linac

A transport system between the RFQ and the drift tube linac comprises a charge stripper (C-foil), a rebuncher and two pairs of quadrupole doublets. The charge stripper is used to increase the charge state of the ions with a small  $q/A$ . The rebuncher is a 25.5-MHz double coaxial quarter wave resonator with six gaps. The power consumption in the cavity is less than 1.5 kW also in a maximum operation.

### 2.3 Drift Tube Linac

The ions with  $q/A \geq 1/10$  are accelerated from 172 keV/u to 1 MeV/u by a 51 MHz interdigital-H (IH) linac. To obtain a high shunt impedance,  $\pi$ - $\pi$  drift tubes without transverse focusing element were adopted. The linac has four separated tanks. The output energy can be continuously varied in the whole energy range from 172 keV/u to 1 MeV/u by adjusting rf power levels and rf phases. Three sets of quadrupole triplets are placed between tanks. The design parameters of the IH linac are listed in Table 2 together with unloaded-Q and effective shunt impedance

Table 1: Design parameters of the SCRFAQ

Frequency	25.5 MHz
Charge-to-mass ratio	$\geq 1/30$
Energy	2 $\rightarrow$ 172 KeV/u
Input emittance	291 $\pi$ mm·mrad
Normalized emittance	0.6 $\pi$ mm·mrad
Vane length	8.585 m
Number of cells (radial matcher)	172(20)
Max. Intervane voltage	108.6 kV
Max. surface field	178.2 kV/cm (2.49 Kilpatrick)
Mean aperture radius ( $r_0$ )	0.9846 cm
Minimum aperture radius ( $a_{min}$ )	0.5388 cm
Max. modulation index ( $m_{max}$ )	2.53
Margin of bore radius ( $a_{min}/a_{beam}$ )	1.2
Final synchronous phase	-30°
Focusing strength (B)	5.5
Max. defocusing strength ( $\Delta_b$ )	-0.17
Transmission (0 mA input)	91.4 %
Transmission (5 mA input)	86.0 %

( $Z_{eff}$ ) obtained from low power measurements. The power consumptions were estimated from the effective shunt impedance measured by a bead-pull method.

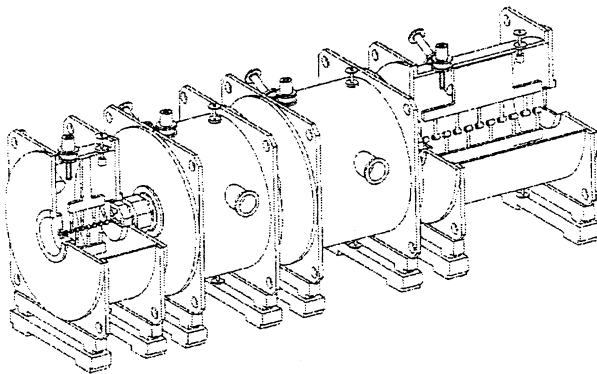


Figure 3: IH linac view.

### 3 ACCELERATION TEST USING STABLE BEAM

Tests using stable beams have been done in order to know the performance of the linac complex. The stable beams were produced by a compact 2.45GHz ECR ion source, mass-analyzed by a bending magnet and two quadrupole magnets, and injected into the SCRFAQ.

#### 3.1 RFQ beam test

The stable beams,  $H_2^+$ ,  $He^+$ ,  $N_2^{2+}$ ,  $Ne^{2+}$ ,  $N^+$ ,  $Ar^{2+}$  and  $N_2^+$  were successfully accelerated by the RFQ so far. The inter-

Table 2: Main parameters of the IH linac

	tank1	tank2	tank3	tank4
f(MHz)	51	51	51	51
max. $q/A$	1/10	1/10	1/10	1/10
$T_{out}$ (MeV/u)	0.294	0.475	0.725	1.053
$L_{tank}$ (m)	0.68	0.90	1.16	1.53
$D_{tank}$ (m)	1.49	1.49	1.49	1.34
$D_{bore}$ (cm)	2.0	2.4	2.8	3.2
$D_{tube}$ (cm)	3.8	4.4	4.6	5.2
$L_{gap}$ (cm)	2.9	3.7	4.5	5.3
Cell No.	9	10	11	12
$V_{gap}$ (kV)	200	250	313	370
unloaded-Q	10681	15387	16230	18490
$Z_{eff}$ (M $\Omega$ /m)	264	289	268	218
P(kW)	10.5	15	25	39

vane voltages corresponding to these accelerations range from 7.2 to 101 kV. Figure 4 shows the beam transmission of the RFQ as a function of intervane voltages. At the design intervane voltages, the measured transmission efficiencies for the accelerated ions (solid circle) are about 90%, which agree with the prediction by the PARMTEQ-H simulation (solid line).

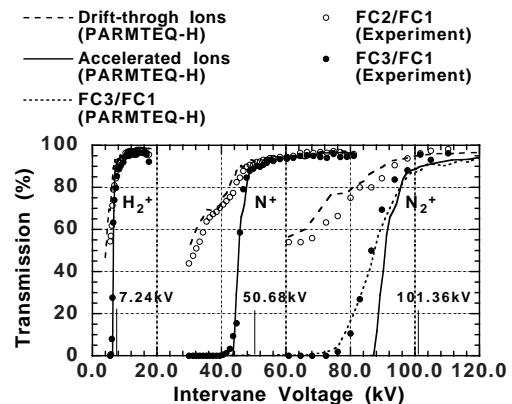


Figure 4: Transmission efficiency as a function of the intervane voltage.

#### 3.2 Beam transmission of the linac complex

Figure 4 shows the transmission efficiency of the  $^{14}N^{2+}$  beam through the whole linacs. The transmission efficiency through the IH linac is 100% (see DTL IN and DTL OUT). If the effect of particles not accelerated by the RFQ is taken into account at RFQ OUT, the transmission efficiency of the transport line between the RFQ and the IH linac is also estimated to be near 100%.

#### 3.3 Energy variable mode of the IH linac

A variability of the output energy was confirmed in  $^{14}N^{2+}$  beam test. Figure 5 shows a preliminary result of the output

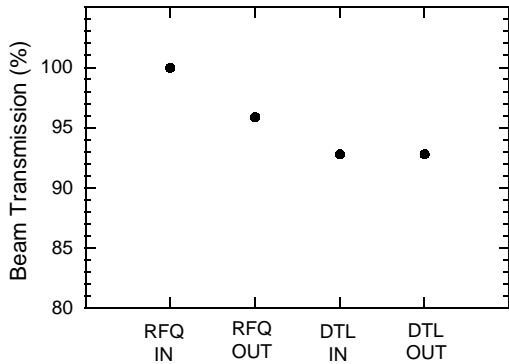


Figure 5: Transmission efficiency of the linac complex.

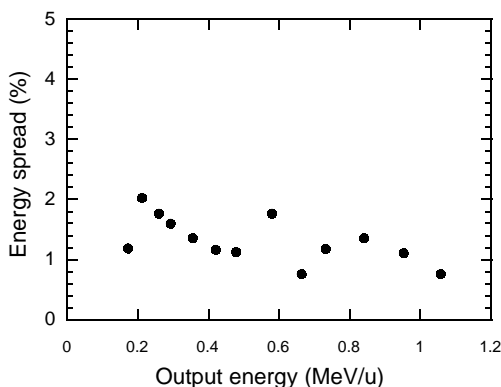


Figure 6: Variable energy and its spread obtained by the IH linac.

energies and their spreads. The energy spreads in the figure are expressed by 2 rms width  $\Delta T/T$  for 90% particles. The rf power and its phase for each output energy were set to the values predicted by the simulation. The transmission efficiencies for all energies were over 80%, though the tuning of the quadrupole magnets were not enough. The measured output energies well agree with the simulated ones. The measured energy spreads for several output energies are rather less than the simulated ones. We will investigate the reason.

### 3.4 Deceleration by the IH linac

It is possible to decelerate the beam from the RFQ by the first IH tank. The beam bunch from the RFQ is injected into a deceleration phase of the first IH-tank. In the deceleration test of  $\text{He}^+$ , the rf phase of the first IH-tank was set to +135 degree. Obtained output energy was 134 KeV/u for the design gap voltage ( $V_n=1$ ) of the first IH tank, and 112 KeV/u for  $V_n=1.8$ .

### 3.5 Beam test of a stripping foil

The test of a carbon stripping foil was done by using  $^{14}\text{N}^{2+}$  beam[3]. A result of the beam test are summarized in Table 3. The thickness of the carbon foils is 10 and 15  $\mu\text{g}/\text{cm}^2$ . The energy loss and straggling well agree with the estimated values. The beam transmission efficiency was  $\sim 60\%$  of that expected for a most probable charge state ( $q=3+$ ). A fine tuning of the transverse focusing elements is necessary to increase it. In the next test, a growth rate of the transverse emittance will be also measured.

Table 3: Measured energy loss and its straggling

Thickness ( $\mu\text{g}/\text{cm}^2$ )	0	10	15
energy loss (KeV/u)	0.0	7.7	11.9
energy spread (KeV/u)	2.9	3.9	4.2
energy straggling (KeV/u)	0.0	1.0	1.3

## 4 FIRST ACCELERATION OF RADIOACTIVE NUCLEI

First acceleration test of  $^{19}\text{Ne}^{2+}$  ( $T_{1/2}=17.3$  s) was conducted [4]. The  $^{19}\text{Ne}$  beam was produced using  $^{19}\text{F}(p, n)$  reaction with 30 MeV-protons from the SF cyclotron. The production rate in the target is estimated to be  $2 \times 10^9$  with 1  $\mu\text{A}$ , 30 MeV protons. The ISOL-ECR ion source was in a pulse operation, 2.0 ms in width and 100 Hz in repetition rate, which were determined by the operation of the linac complex. The IH tank-1 through tank-3 were operated to accelerate  $^{19}\text{Ne}$  up to 0.72 MeV/u. The  $^{19}\text{Ne}$ -transmission efficiency of the linac complex is estimated to be over 80% from the contaminated beam current measured by Faraday cups. The intensity delivered to a secondary target is not yet enough. Further improvements will be done to perform experiments using accelerated radioactive nuclei.

## 5 REFERENCES

- [1] T. Nomura: 'Exotic Nuclei Arena in Japanese Hadron Project', INS-Report-780(1989).
- [2] S. Arai *et al.*: 'Construction and Beam Tests of a 25.5-MHz Split Coaxial RFQ for Radioactive Nuclei', Nucl. Instr. and Meth., **A390**(1997)9.
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