DP

INS Report

INS-Rep.-1172
Nov. 1996

STATUS OF THE INS HEAVY ION LINAC FOR SHORT-LIVED NUCLEAR BEAMS

K. Niki, S. Arai, Y. Arakaki, Y. Hashimoto, A. Imanishi, T. Katayama, H. Masuda†, M. Okada, Y. Takeda, E. Tojyo, N. Tokuda††, M. Tomizawa, K. Yoshida††† and M. Yoshizawa

Institute for Nuclear Study, University of Tokyo
3-2-1 Midori-cho, Tanashi, Tokyo 188, Japan
† Computer Centre, University of Tokyo
2-11-16 Yayoi, Bunkyou, Tokyo 113, Japan
†† KEK, National Laboratory for High Energy Physics
1-1 Oho, Tsukuba, 305 Japan
††† Hiroshima Synchrotron Radiation Center, Hiroshima University
1-3-1 Kagamiyama, Higashi-hiroshima, Hiroshima 739, Japan

Presented at the 6th China-Japan Joint Symposium
on Accelerators for Nuclear Science and Their Applications,
Chengdu, China, 21-23 October, 1996

Institute for Nuclear Study
University of Tokyo
Tanashi, Tokyo 188, Japan

STATUS OF THE INS HEAVY ION LINAC FOR SHORT-LIVED NUCLEAR BEAMS

K. Niki, S. Arai, Y. Arakaki, Y. Hashimoto, A. Imanishi, T. Katayama, H. Masuda†, M. Okada, Y. Takeda, E. Tojyo, N. Tokuda††, M. Tomizawa, K. Yoshida††† and M. Yoshizawa
Institute for Nuclear Study, University of Tokyo
3-2-1 Midori-cho, Tanashi, Tokyo 188, Japan
† Computer Centre, University of Tokyo
2-11-16 Yayoi, Bunkyou, Tokyo 113, Japan
†† KEK, National Laboratory for High Energy Physics
1-1 Oho, Tsukuba, 305 Japan
††† Hiroshima Synchrotron Radiation Center, Hiroshima University
1-3-1 Kagamiyama, Higashi-hiroshima, Hiroshima 739, Japan

Abstract

A linac complex for radioactive beams has been constructed at INS, which comprises a 25.5-MHz split coaxial RFQ (SCRFQ) and a 51-MHz interdigital-H (IH) linac . The SCRFQ accelerates ions with a charge-to-mass ratio (q/A) greater than 1/30 from 2 to 172 keV/u. The beam from the SCRFQ is charge-stripped by a carbon-foil, and is transported to the IH linac through two magnetic-quadrupole doublets and a 25.5-MHz rebuncher cavity. The IH linac accelerates ions with a q/A greater than 1/10, and the output energy is variable in the range of 0.17 through 1.05 MeV/u. The detailed beam tests of the SCRFQ were conducted with a N^+ beam. The measured results agreed well with PARMTEQ simulations. The acceleration tests of the linac complex were conducted with N^{2+} and Ne^{2+} beams. The measured output-beam energies, transmission efficiencies and emittances almost agree with predictions. Finally, we could accelerate ions with q/A=1/10 up to near 1 MeV/u.

Introduction

As a prototype facility of the exotic-nuclei arena in the Japanese Hadron Project (JHP) [1], a heavy ion linac complex for radioactive beams has been constructed at INS since fiscal year 1992. The layout of the linac system is shown in Fig. 1. The linac system comprises a low-energy beam transport (LEBT), a 25.5-MHz split

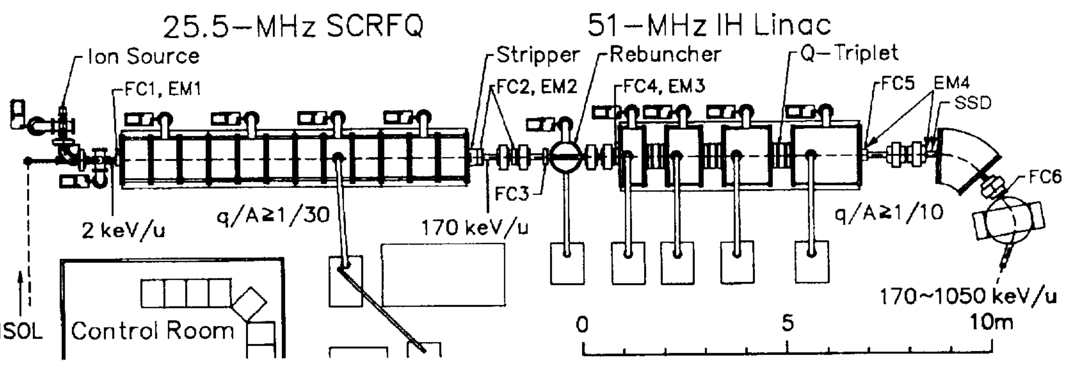

Figure 1: Heavy-ion linac complex at INS.

coaxial RFQ (SCRFQ), a medium-energy beam transport (MEBT), a 51-MHz interdigital-H (IH) linac, and a beam-energy analyzer section in the high-energy beam transport (HEBT). Either unstable nuclei or stable ones are injected to the SCRFQ through the LEBT. Stable-nucleus ions are produced in a 2.45-GHz ECR ion source located near to the SCRFQ. The SCRFQ with modulated vanes, 0.9 m in inner diameter and 8.6 m in length, accelerates ions with a charge-to-mass ratio (q/A) greater than 1/30 from 2 to 172 keV/u [2]. The beam from the SCRFQ is charge-stripped by a carbon-foil so that q/A becomes greater than 1/10, and is transported to the IH linac through two magnetic-quadrupole doublets and a 25.5-MHz rebuncher cavity [3]. The IH linac, 5.63 m in total length, consists of four tanks and three magnetic-quadrupole triplets between the tanks [4]. The tanks are excited separately by four rf power sources. It is therefore possible to vary the output beam energy continuously over a range from 0.17 to 1.05 MeV/u by adjusting the rf power levels and phases.

After the first Ne^{+} beam tests of the SCRFQ, detailed beam tests were conducted with a N^{+} beam in April, 1995. The acceleration tests of the linac complex (SCRFQ/IH) started by using N^{2+} ions in early spring of 1996. The beam accelerated by the SCRFQ was injected to the IH linac without using the stripping foil. On September 20, 1996, we succeeded in the acceleration of the Ne^{2+} beam (q/A=1/10) up to near the designed value of 1.05 MeV/u. This paper describes the beam test results of the SCRFQ and linac complex.

Beam Monitoring System

In order to examine the performance of the SCRFQ/IH linac system, the following beam-monitoring apparatuses were installed in the linac beam transports (See Fig.1). In the LEBT, the double-slit emittance monitor (EM1) and the Faraday cup (FC1) were set at the RFQ entrance. The front and rear slits of the emittance monitor (EM2) in the MEBT were located near to the RFQ exit and between the quadrupole magnets, respectively. The Faraday cup (FC2) measures the current of drift-through ions (both of accelerated and unaccelerated ions by RFQ). Because the first quadrupole doublet downstream the SCRFQ can kick out unaccelerated ions and focus accelerated ones into FC3, the Faraday cup (FC3) can measure the current of accelerated ions only. The emittance monitor (EM3) and the Faraday cup (FC4) were located at the entrance of the IH linac. In the HEBT, the Faraday cup (FC5) with the water cooling and the emittance monitor (EM4) were located at the exit of the IH linac. At the downstream of the IH linac, the momentum analyzing system (Analyzer) was set up. This comprises the quadrupole doublet, the dipole magnet, the vertical slit with a width of 4 mm and a charge collecting plate (FC6). This system has a energy resolution less than 1% for the 1-MeV/u ion beam, which has the designed emittances of the IH linac. The beam energy was estimated from the magnetic field measured by a hole probe. However, for 1-MeV/u ions with a q/A smaller than 1/7, the saturation of the magnetic field is not negligible. Therefore, the solid state detector (SSD; made of Si) was also installed in front of the analyzing magnet for the measurements of the output beam energies. The calibration of the SSD was performed using α beam (5.486 MeV) from the ^{241}Am. The linearity of a system consisting of a pre-amplifier, a shaping amplifier and multi-channel analyzer was measured using a pulse generator with a charged terminator.

Beam Acceleration Tests

Performance of SCRFQ

Through the N^{+} beam tests, the transmission efficiency was measured as a function of the intervane voltage. The nominal intervane voltage for N^{+} is 50.68 kV. The RFQ was operated at 25.47 MHz with a duty factor of 5% (0.53 ms $\times$ 95 Hz), and the ion source synchronized the RFQ. The N^{+} beam current was 0.21 $\sim$ 0.22 mA in peak at FC1. The measured transmission efficiency agreed well with PARMTEQ simulation [2]. At the nominal intervane voltage the measured transmission efficiency is 90%. This is close to the design value (91.4%) of a matched input beam with a normalized emittance (ϵ_n) of 0.06 π cm $\cdot$ mrad. Though the matching condition was rather poor in the y-y' space, we obtained a high transmission. This is due to the RFQ acceptance larger than 0.06 π cm $\cdot$ mrad normalized. The measured output beam emittances and transmission efficiencies show that the performance of the RFQ is close to the designed one.

Performance of the linac complex: SCRFQ/IH

The overall performance of the linac complex was examined by using N^{2+} and Ne^{2+} beams. The average beam currents at the entrance of the SCRFQ were about 100 nA for N^{2+} and 50 nA for Ne^{2+}. The ion source was operated in a pulse mode, 0.6 ms in width and 100 Hz in repetition. The rf pulse widths of the SCRFQ

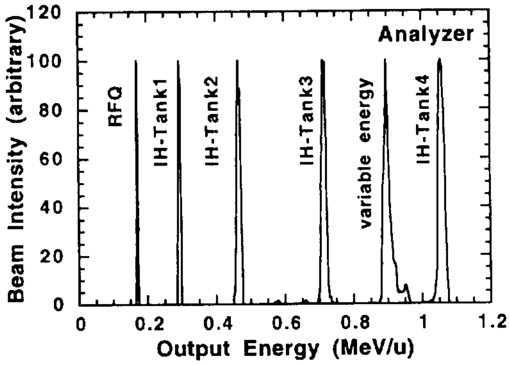

Figure 2: Energy spectra for six operating modes.

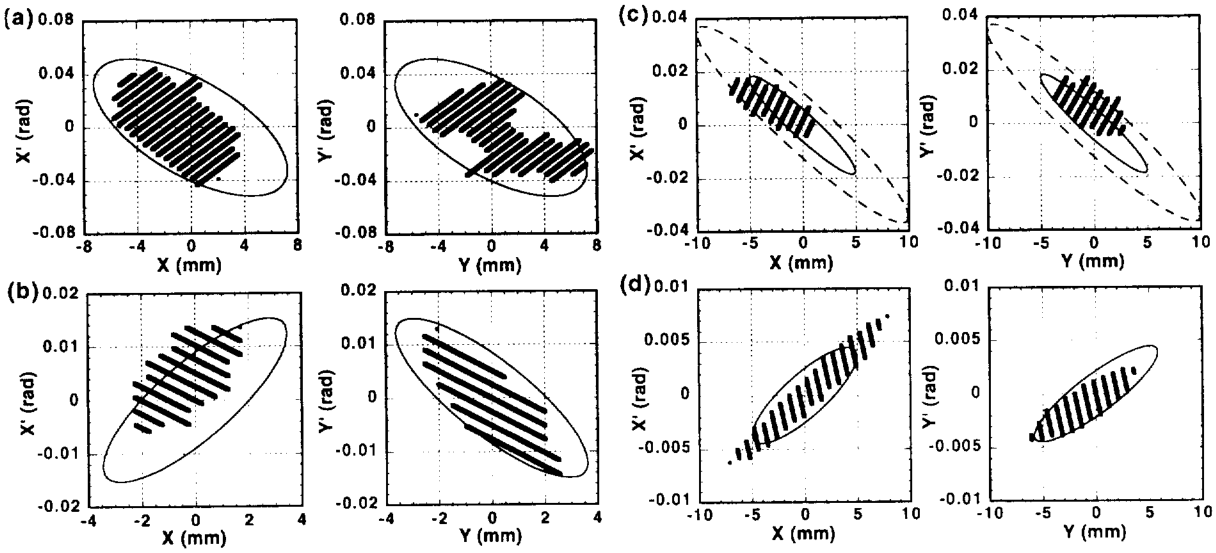

Figure 3: (a) Emittance profiles at the RFQ entrance, (b) at the RFQ exit, (c) at the IH-linac entrance, and (d) at the IH-linac exit.

and IH linac were set to 1.2 ms so as to cover the beam pulse from the ion source. The 25.5 MHz-rebuncher was operated at 100% duty.

We tuned the IH linac as follows: after adjusting the gap voltage and rf phase of each IH tank [5], we optimized parameters of the focusing elements to increase the transmission efficiency of the IH linac. Figure 2 shows the beam energy spectra for N^{2+} ions measured by the analyzer. The tags in the figure show the operation modes. For example, "IH-Tank3" in the figure shows the result obtained when the SCRFQ and the 1st through 3rd IH-tanks are operated and the 4th tank is not operated. As seen from "IH-Tank4", the beam was accelerated up to the maximum design energy, 1.05 MeV/u. The emittance profiles were measured at the RFQ entrance, the RFQ exit, the IH-linac entrance and the IH-linac exit as shown in Fig. 3. The bars indicate measured 90% emittance profiles of a N^{2+} beam, and the solid-line ellipses the designed ones with an area of $\varepsilon_n = 0.06$ π cm·mrad. The broken-line ellipses in figure (c) show the designed acceptance of the IH linac with 0.24 π cm·mrad (normalized).

Figure 4 shows the results of Ne^{2+} beam tests along with that of N^{2+} ones. The total energy spectra were measured by the SSD. The data for N^{2+} ions were obtained in the same condition as "IH-Tank4". The beam was accelerated up to 1.05 MeV/u and the transmission efficiency of the IH linac was almost 100%, which was defined by the ratio of the beam current at FC5 to one at FC4. On the other hand, the data for Ne^{2+} ions

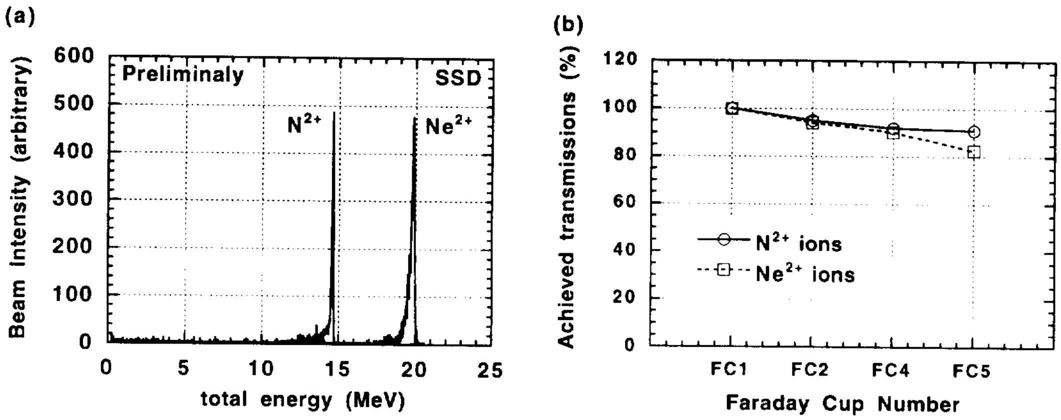

Figure 4: (a) Energy spectra and (b) transmissions measured at each Faraday cup for N^{2+} and Ne^{2+} beams.

indicates the output energy is slightly small compared with the designed value, 1.05 MeV/u, because the rf power supply of the 4th tank was not operated at design power level due to the limit of the screen grid current.

Concluding Remarks

The beam tests of the SCRFQ with a N^+ beam showed following results: 1) the transmission efficiency exceeds 90% at a design voltage, 2) the form of the transmission measured as a function of the intervane voltage and the emittance profiles of the output beam agree well with PARMTEQ predictions.

The beam tests of the SCRFQ/IH linac with N^{2+} and Ne^{2+} beams showed following results: 1) the output beam energy and its spread agree fairly well with the design values, when the gap voltage and accelerating phase of each tank of the rebuncher and IH linac are set to the design values [5]. 2) the transmission efficiency of the IH linac is almost 100%, when the transverse focusing elements are optimized.

Acknowledgments

We express our thanks to T. Nomura for his encouragement, and M. Wada for his help in the beam tests. The SCRFQ and IH linac were fabricated by Sumitomo Heavy Industries, Niihama Work. The rf power sources were fabricated by Denki Kogyo Co., Ltd, and IDX Corporation. The HEBT was constructed by stuff in nuclear physics division at INS. The beam monitors were fabricated by the INS machine shop. The computer works were done on FACOM M780, VP2100 and SUN-4/1000 in the INS Computer Room.

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", INS-Rep.-1152 (1996).

[3] K. Yoshida *et al.*, "Model Test of a Double-Coaxial $\lambda/4$ Resonant Cavity as a Rebuncher", Proc. 1994 Int. Linac Conf., Tsukuba, 1994, p. 771.

[4] M. Tomizawa *et al.*, "Model Measurement and Present Status of Interdigital-H Linac at INS", ibid., p. 765.

[5] S. Arai *et al.*, "BEAM TEST RESULTS OF THE INS RFQ/IH LINAC", Proc. 1996 Linear Acc. Conf., Switzerland, August 1996.