Acceleration Tests of the Folded-Coaxial RFQ Linac for the RILAC

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Abstract

A new injector for the RIKEN heavy-ion linac (RILAC) has been installed, which consists of a variable-frequency RFQ and an 18-GHz ECR ion source. The RFQ, based on a folded-coaxial resonator with a movable shorting plate, accelerates ions with mass-to-charge ratios of 6 to 26 at up to 450 keV per charge in the cw mode by varying the resonant frequency from 18 MHz to 39 MHz. Acceleration tests of the RILAC and the ring cyclotron (RRC) were successfully performed with the new injector. The beam intensity from the RRC as well as the transmission efficiency through the RILAC has been greatly improved.

1 Introduction

The RIKEN heavy-ion linac (RILAC) is rf frequency-tunable between 17 MHz and 40 MHz, which accelerates various kinds of ions with mass-to-charge (m/q) ratios up to 28 in a wide energy range[1]. A 450-kV Cockcroft-Walton accelerator with an 8-GHz electron-cyclotron resonance ion source (ECRIS) has been used as the injector of the RILAC.

In order to increase beam intensities in the RILAC, a new injector has been constructed[2], which consists of an 18-GHz ECRIS[3] and a variable-frequency RFQ linac. This injector was installed in the RILAC beam line in August, 1996, as shown in Fig. 1, while keeping the beam line from the Cockcroft-Walton injector alive.

Table: 1 Main Parameters of the FCRFQ

	~ 07.1997	08.1997 ~
Frequency (MHz)	17.7 - 39.2	17.4 - 39.0
Mass-to-charge ratio (m/q)	6 - 26	6 - 26
Input energy (keV/q)	10	20
Output energy (keV/q)	450	450
Input emittance (mm•mrad)	145 π	145 π
Vane length (cm)	142	153
Intervane voltage (kV)	33.6	36.8
Mean aperture (r_0:mm)	7.70	8.08
Min. aperture (a_{min}:mm)	4.17	4.67
Max. modulation (m)	2.70	2.41
Focusing strength (B)	6.8	6.8
Max. defocusing strength	-0.30	-0.30
Final synchronous phase	-25°	-30°

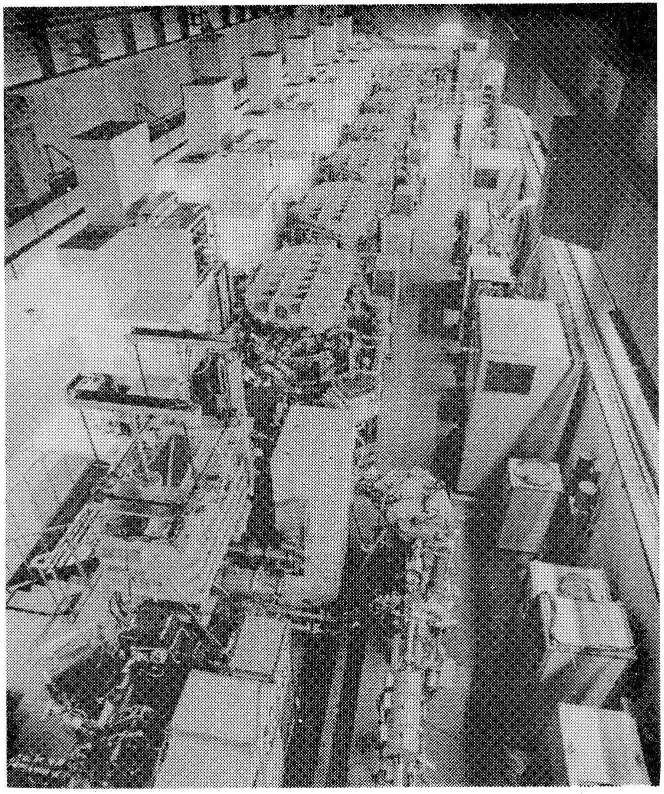

Figure: 1 Photograph of the RILAC along with the RFQ.

2 FCRFQ linac

The RFQ resonator is based on a folded-coaxial structure[4]. The distinct features of this folded-coaxial RFQ (FCRFQ) are that it can be operated in a low frequency region and the frequency range is quite large. The main parameters are listed in Table 1.

Figure 2 shows a schematic layout of the FCRFQ resonator whose details are given in the reference[4]. The resonator is separable into upper and lower parts, as shown in the figure. All the vanes are rigidly fixed in the lower part. The upper part containing the stem and the movable shorting plate can be removed as a unit. This separable structure permits accurate alignment of the vanes and easy maintenance. The lower part of the tank-wall is made of steel (SS400) whose inside is plated with copper to a thickness of 100 μm, while the other parts such as the vanes and the stem are made of oxygen-free copper (C1020). The vanes are three-dimensionally machined within the accuracy of ±50 μm.

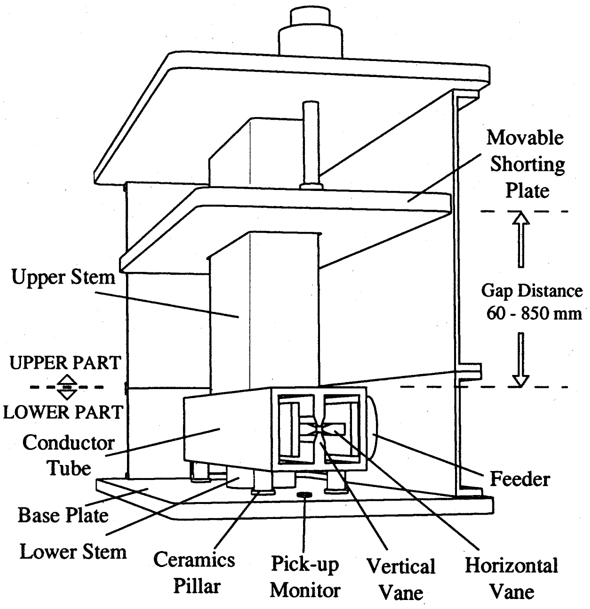

Figure: 2 Schematic drawing of the RFQ resonator. The inner volume of the resonator is about 1700 mm (length) × 700 mm (width) × 1150 mm (height).

The channels for water cooling are arranged based on a heat analysis. The total water flow is 155 *l*/min at the pressure of 7 atm. The resonator is evacuated by two turbo-molecular pumps (1500 *l*/s) on its both sides. The vacuum stays in a range of 5 - 8 × 10^{-8} Torr at the pump head during the operation.

The rf power is supplied through a capacitive feeder with an rf power source based on an Eimac 4CW50000E, which has a cw power of 40 kW at maximum between 16.9 and 40 MHz. A capacitive tuner for the fine tuning is placed on the other side of the feeder.

The resonant frequency varies from 18 MHz to 36 MHz by changing the position of the shorting plate by a stroke of 790 mm, when the lower stem is out of the resonator. When the lower stem is used, the frequency varies from 30 MHz to 39 MHz. The maximum power losses are 6 kW at 18 MHz and 26 kW at 39 MHz in the cw operation.

The key to the stable operations of this RFQ is the ceramics pillar, which stands up to the high rf-voltage. Figure 3 shows the structure of the pillar installed in the resonator. It consists of Al_2O_3, whose nominal loss-tangent is 2 × 10^{-4}, welded with copper-tungsten alloy on its both sides. This welding is possible because both materials have similar values of the coefficient of the linear thermal expansion. Since there is no electric field concentration in the ceramic material, it is quite stable even in the operation at the maximum voltage. The power loss in one pillar is estimated to be 20 W at maximum.

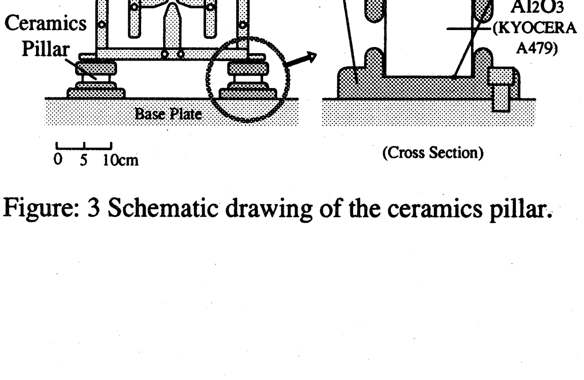

Figure: 3 Schematic drawing of the ceramics pillar.

3 Acceleration Test

3.1 Preliminary Test

Prior to the installation in the RILAC beam line, we tested the new injector alone by using Oxygen, Neon, Argon, Krypton and Tantalum beams[5]. They are indicated by the closed circles in Fig. 4. The maximum transmission efficiency was 88 % for an Ar^{8+} beam of 120 eμA.

The input beam emittance from the ion source was measured to be 150 - 300 π mm•mrad, which decreased as the extraction voltage and/or the charge states of the ions increased. The output beam emittance was almost independent of the acceleration condition and was in agreement with the PARMTEQ simulation.

The energy distribution of the output beam was measured with an electrostatic deflector placed downstream of the RFQ along with a scanning wire probe. The beam energy was deduced from the beam position measured with the probe, and the voltage applied to the deflector. The measured distributions were found to be well reproduced by the PARMTEQ simulation. The energy spread of the output beam was also measured with the same device. The result was 2-3% at FWHM and was consistent with the simulation.

3.2 Test of the RILAC

The beam matching section between the RFQ and the RILAC consists of two quadrupole doublets and one rebuncher operated in the fundamental harmonics[6]. The rebuncher resonator is a quarter-wavelength type with four gaps, which is driven by a 1-kW wide-band amplifier. A capacitive phase probe, placed in a chamber before the RILAC, was shown to be important in adjusting the rf phase of the rebuncher.

The ions accelerated through the RILAC with the new injector so far are $N^{2,3+}$, $Ar^{2,4,5+}$, Fe^{7+}, Ni^{8+}, $Kr^{5,11,18+}$, Te^{18+} and $Xe^{7,17,19+}$ at various frequencies. They are indicated by the diamonds and the open circles in Fig. 4.

The transmission efficiency of the RILAC has increased to 70 %, while the original value for the beams from the Cockcroft-Walton injector was 30 %. In the tests, however, the transmission efficiency of the injector section was about 70 %, which was lower than that obtained in the preliminary tests. Therefore, about one half of the ions extracted from the 18-GHz ECRIS were accelerated by the RILAC. This overall efficiency is three times larger than the original value of 15 %. The maximum beam intensity ever accelerated through the RILAC with the new injector is 13 pμA for a N^{3+} beam of 2.5 MeV/nucleon.

3.3 Test of the Ring Cyclotron (RRC)

In December, 1996, we started the acceleration tests of the ring cyclotron (RRC) with the upgraded RILAC. The ions accelerated so far are Ar^{5+}, Fe^{7+}, Ni^{8+}, Te^{18+}, Kr^{18+} and $Xe^{17,19+}$at the frequencies of 18.0, 18.8, 19.1, 20.5, 22.9 and 28.1 MHz. They are indicated by the open circles in Fig. 4.

In the first test using an $^{36}Ar^{5+}$ beam, we achieved the beam current of 1 pμA out of the RRC for the first time, where 20 % of the beam extracted from the ion source was accelerated to the final energy of 7.5 MeV/nucleon.

The charge strippers after the RILAC has become unnecessary for the low-energy beams mentioned above, because highly charged ions are now available with the 18-GHz ECRIS. This is an advantage from the viewpoint of the beam intensity and the stability.

3.4 Test with the New Vanes

Since August, 1997, the maximum extraction voltage of the ECRIS has been raised to 20 kV in order to further upgrade the beam intensity. The parameters of the new vanes for the upgraded beams are listed in Table 1. As a preliminary test, we accelerated Argon ions through the RILAC at 18.8 MHz, and found that the overall transmission efficiency improved to be 62 %. The transmission efficiency of the injector section was 83 %. More tests with the new vanes will be performed in this year.

4 Summary

We installed the new injector for the RILAC, which consists of the 18-GHz ECRIS and the FCRFQ. The transmission efficiency of the RILAC exceeds 70 % now. Moreover, we achieved the beam current of 1 pμA out of the RRC for the first time.

The maximum extraction voltage of the ECR ion source has been raised recently, and further acceleration tests will be performed in this year. In the future, this new injector is expected to play an important role in the RI-beam factory project[7].

5 Acknowledgments

The authors are grateful to Dr. N. Tokuda at KEK and Dr. S. Arai at INS for the usage of the program for vane-cutting as well as for the fruitful information about the vane design. They are also grateful to the operation staffs of the RILAC and the RRC for their efforts in the installation and the improvement. The resonator was fabricated by Sumitomo Heavy Industries, Niihama Work, the rf power source by Denki Kogyo, and the ceramics pillars by KYOCERA Corporation.

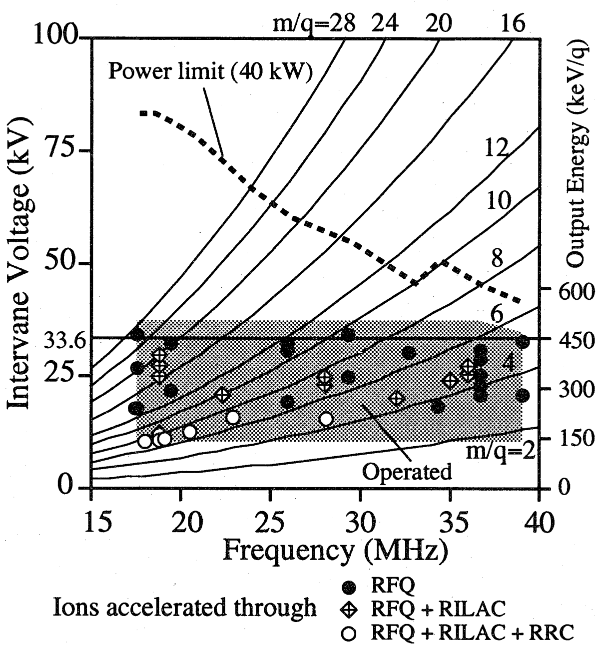

Figure: 4 Performance of the RFQ linac. The abscissa and the ordinate represent the resonant frequency and the intervane voltage, respectively. The output energy, which is proportional to the intervane voltage, is also indicated. The hatched area shows the region where the RFQ has ever been operated in the cw mode. The ions accelerated so far are indicated by the closed circles, the diamonds, and the open circles. The solid curves represent the acceleration condition of ions, each of which is indicated by the m/q-value. The dashed curve shows the maximum attainable voltage with the present power source (40 kW).

References

[1] M. Odera *et al.*, Nucl. Instrum. and Methods, **227**, 187 (1984).

[2] A. Goto *et al.*, Proc. 14th Int. Conf. on Cycrotrons and Their Applications, 1995, Cape Town, p. 237 (1995).

[3] T. Nakagawa *et al.*, "Recent Progress of RIKEN 18 GHz ECRIS", 1997 Particle Accelerator Conference, 1997, Vancouver (1997).

[4] O. Kamigaito *et al.*, Jpn. J. Appl. Phys. **33**, L537 (1994), and Jpn. J. Appl. Phys. **34**, 5799 (1995).

[5] O. Kamigaito *et al.*, Proc. 18th Int. Linear Accelerator Conference, 1996, Geneva, p. 863 (1996)

[6] O. Kamigaito *et al.*, RIKEN Accel. Progr. Rep. **30**, p.191 (1996).

[7] Y. Yano, "RIKEN RI-Beam Factory Project", 1997 Particle Accelerator Conference, 1997, Vancouver (1997).