ACCELERATION TEST OF THE FOLDED-COAXIAL RFQ LINAC FOR THE RILAC

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Abstract

A new injector system for the RIKEN heavy-ion linac (RILAC) has been constructed, 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 17.7 to 39.2 MHz. Beam tests of the RILAC and the ring cyclotron (RRC) were successfully performed with the new injector system. The beam intensity from the RRC as well as the transmission efficiency through the RILAC has been greatly improved. This paper describes the performance of the RFQ and the results of the acceleration tests.

1 INTRODUCTION

The RIKEN heavy-ion linac (RILAC) is rf frequency-tunable between 17 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.

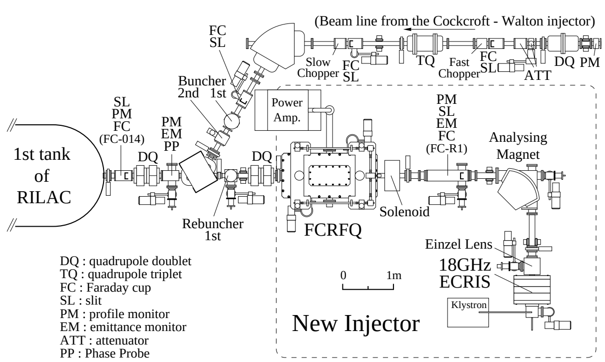

Figure: 1 Schematic drawing of the new injector for the RILAC

In order to increase beam intensities in the RILAC, a new injector has been constructed recently[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. In this paper we describe the results obtained from the acceleration tests which started at the end of October, 1996 as well as the outline of the RFQ linac.

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 design parameters are listed in Table 1.

Table: 1 Design Parameters of the FCRFQ

Frequency	17.7 - 39.2 MHz
Mass-to-charge ratio (m/q)	6 - 26
Input energy	10 keV/q
Output energy	450 keV/q
Input emittance	145 π mm•mrad
Vane length	1420 mm
Intervane voltage	33.6 kV
Mean aperture radius (r_0)	7.70 mm
Minimum aperture radius (a_{min})	4.17 mm
Maximum modulation (m)	2.70
Focusing strength (B)	6.8
Max. defocusing strength	-0.30
Final synchronous phase	-25°

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 mm, 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. They are aligned within the same accuracy by taking the estimation of the misalignment effect on the beam transmission efficiency into account[6].

The channels for water cooling are arranged based on a heat analysis. Water for the horizontal vanes is supplied through the front and rear supports of the vanes. That for the vertical vanes and the rectangular tube is provided through the inside of the upper stem. 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 a pump head during the operation.

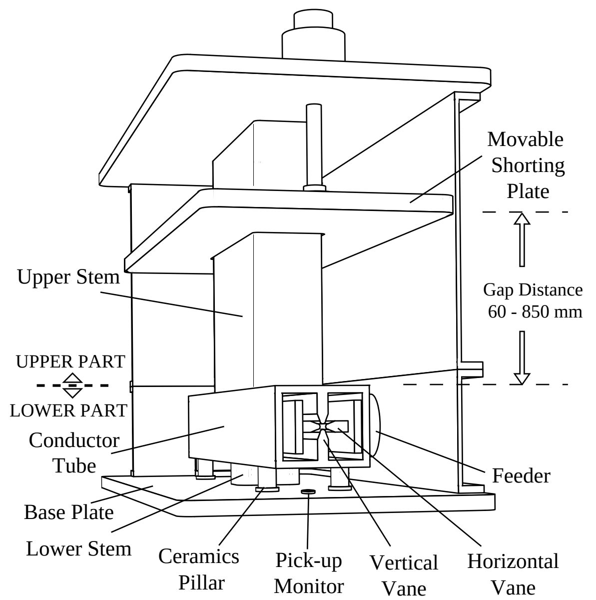

Figure: 2 Schematic drawing of the RFQ resonator. The inner volume of the resonator is about 1700 mm (length) × 700 mm (width) × 1150 mm (height).

The 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 17.7 to 36.2 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 30.2 to 39.2 MHz. This result is in good agreement with the MAFIA calculation. On the other hand, the measured Q-values and the shunt impedances are about half of the MAFIA calculations. The power losses estimated from the measured shunt impedances are 6 kW at 17.7 MHz and 26 kW at 39.2 MHz for the maximum intervane voltage of 33.6 kV in the cw operation.

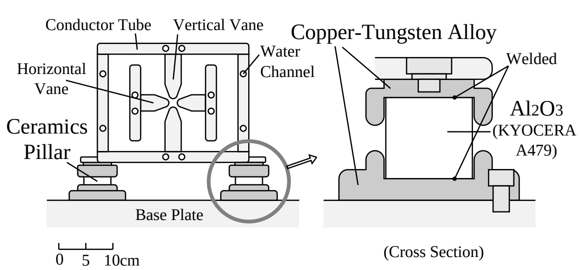

Figure: 3 Schematic drawing of the ceramics pillar.

The key to the stable operations of this RFQ is the ceramics pillar, which stands 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 of the maximum voltage. The power loss in one pillar is estimated to be 20 W at maximum.

3 ACCELERATION TEST

3.1 Preliminary Test

Prior to the installation in the RILAC beam line, we tested the new injector system alone by using Oxygen, Neon, Argon, Krypton, and Tantalum beams[6]. They are indicated by the closed circles in Fig. 4. The maximum transmission efficiency was 88 % with an Ar^{8+} beam of 120 eμA.

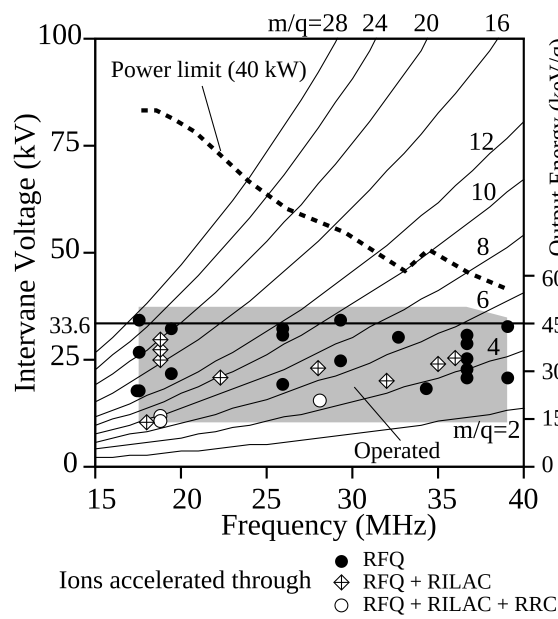

Figure: 4 Performance of the RFQ linac. The abscissa and the ordinate represent the resonant frequency and the intervane voltage, respectively. The output energy, which is proportional to the intervane voltage, is also indicated. The hatched area shows the region where the RFQ has ever been operated 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).

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 the electrostatic deflector placed downstream of the RFQ along with the 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, as shown in Fig. 1[7]. The rebuncher resonator is a quarter-wavelength type with four rf gaps, which is driven by a 1-kW wide-band amplifier. A capacitive phase probe, placed in the chamber before the RILAC, was shown to be important in adjusting the rf phase of the rebuncher.

The ions accelerated so far through the RILAC with the new injector are $N^{2,3+}$, $^{36}Ar^{5+}$, $Ar^{2,4,5+}$, Fe^{7+}, $Kr^{11,18+}$, and Xe^{7+} at the frequencies of 18.0, 18.8, 22.3, 28.0, 28.1, 35.0, 36.0 MHz. They are indicated by the diamonds 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 beam tests, however, the transmission efficiency of the injector section did not reach the value obtained in the preliminary tests. This deterioration might come from the small aperture radius of the rebuncher. Therefore, about one half of the ions extracted from the 18-GHz ECRIS are accelerated by the RILAC at present. Nevertheless, this overall efficiency is three times larger than the original value of 15 %. The maximum beam intensity ever achieved by 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 $^{36}Ar^{5+}$, Fe^{7+}, and Kr^{18+} at the frequencies of 18.8 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.

Since highly charged ions are available with the 18-GHz ECRIS, charge strippers are unnecessary for the low-energy beams of medium-heavy ions. This is an advantage from the viewpoint of the beam intensity and the stability. However, the extraction voltage of the ECRIS becomes quite low for the highly charged ions, because the maximum voltage is 10 kV at present. For example, the extraction voltage was only 3 kV in the first test described above. This low voltage causes bad effects both on the intensity and the emittance of the extracted beams.

We are planning, therefore, to raise the maximum extraction voltage of the 18-GHz ECRIS from 10 kV to 20 kV in this summer. New vanes are under fabrication so that the RFQ can accept the upgraded beams.

4 SUMMARY AND OUTLOOK

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

Since the extraction voltage is too low for the highly charged ions, we are planning to raise the maximum extraction voltage of the ECRIS from 10 kV to 20 kV in this summer for further upgrade of the beam intensity. It is expected that this new injector will play an important role in the RI-beam factory project[8].

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