DEVELOPMENT OF A FOLDED-COAXIAL RFQ LINAC FOR THE RILAC

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Abstract

A variable-frequency RFQ linac which will be used for a new injector of the RIKEN heavy-ion linac (RILAC) has been constructed. This paper describes the results of the performance tests as well as the design of the real structure. 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. Low power tests of the resonator have shown that the power losses are 6 kW at 17.7 MHz and 26 kW at 39.2 MHz for the maximum intervane voltage of 33.6 kV. Stable operations have been achieved in the range of the intervane voltage from 10 kV to 40 kV. Acceleration tests in the cw mode have also been performed using several ion beams at various frequencies. The new injector system consisting of this RFQ and an 18-GHz ECRIS will be installed in the RILAC by the end of 1996.

Introduction

The RIKEN heavy-ion linac (RILAC) is rf frequency-tunable between 17 and 40 MHz[1], which allows us to accelerate various kinds of ions with mass-to-charge (m/q) ratios up to 28 in a wide energy range. 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.

Recently a new injector system of the RILAC has been constructed, which consists of an 18-GHz ECRIS and a variable-frequency RFQ linac, in order to meet growing demands for much more intensity of heavy ion beams in the RILAC. In this paper we describe some results obtained from the performance tests of the RFQ as well as the outline of the RFQ resonator.

RFQ Resonator

The RFQ resonator is based on a folded-coaxial structure[2]. The distinct features of this RFQ are that it can be operated in a low frequency region and the frequency range is quite large.

Figure 1 shows a schematic layout of the RFQ resonator. Horizontal vanes are held by front and rear supports fixed on the base plate. Vertical vanes are fixed on the inner surfaces of a rectangular tube which surrounds the horizontal vanes. This tube is supported by four ceramic pillars placed on the base plate. The lower stem is used only in high-frequency operations where it is in electric contact with both the conductor tube and the base plate, while it is detached from the tube in low-frequency operations. This stem was found to reduce the power consumption because it shares the rf electric current with the upper stem[3].

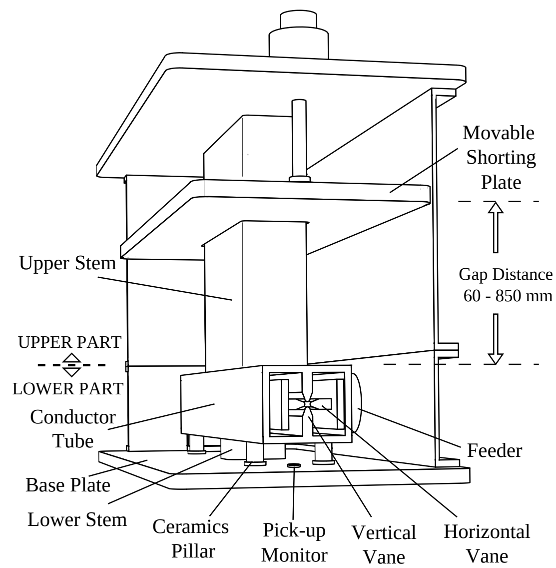

Fig. 1. Schematic drawing of the RFQ resonator. The inner volume of the resonator is about 1700 mm (length) × 700 mm (width) × 1150 mm (height). The vane length is 1420 mm.

The resonator is separable into upper and lower parts, as shown in Fig. 1. 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 channels for water cooling are arranged based on the 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 vanes are three-dimensionally machined within the accuracy of ±50 μm. The vane parameters were determined by taking the results of a numerical simulation into account[4]. Misalignment effect on the beam transmission efficiency was also estimated[4].

Performance Tests

Low Power Tests

The resonant frequency was measured as the first step of the tests. When the lower stem is out of the resonator, 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 it is used, the frequency varies from 30.2 to 39.2 MHz. This result is in good agreement with the MAFIA calculation.

Figure 2 shows the measured Q-values and shunt impedances. The corresponding MAFIA-calculation curves are shown in the figures as well. The shunt impedance R_S is defined by $V^2/(2P)$, where P is the rf power consumption and V is the intervane voltage. As shown in the figure, the measured Q-values and shunt impedances with the lower stem are larger than those without the stem at above 30 MHz.

The MAFIA calculations overestimate the measured values by about 50 %. This is considered to result from the fact that the calculation does not realistically treat the roughness of the wall surface and the imperfection of the electric contact.

The power losses estimated from the 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.

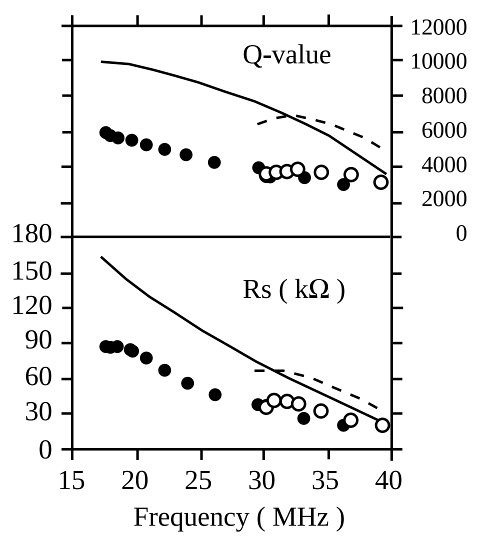

Fig. 2. Measured Q-values and the shunt impedances along with the MAFIA calculations. The closed circles and the solid curve represent the measured and the calculated values, respectively, when the lower stem is detached from the conductor tube. The open circles and the dashed curve represent the measured and the calculated values, respectively, when the stem is used.

High Power Tests

High power tests was carried out with an rf power source based on an Eimac 4CW50000E, which has a cw power of 40 kW at maximum between 16.9 MHz and 40 MHz.

In the first stage of the tests we encountered a problem on the ceramics pillars. When the intervane voltage was above 25 - 30 kV, the pillars were broken by the heat due to the dielectric losses around the metal screws fixing the pillars to the conductor tube.

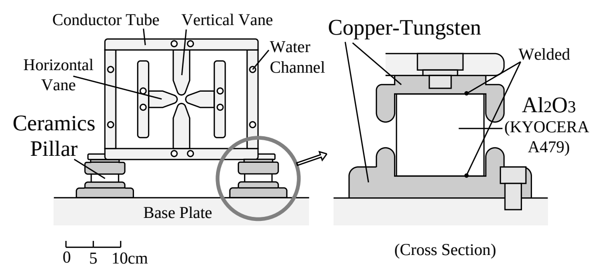

Fig. 3 Schematic drawing of the improved ceramics pillar.

This problem has been solved by adopting the structure of the pillars illustrated in Fig. 3, which consists of Al_2O_3 welded with copper-tungsten metal on its both sides. This welding is possible because both materials have similar values of the coefficient of the linear thermal expansion. After this improvement, the RFQ has been stably operated in the whole range of the acceleration voltage acceptable by the RILAC as shown in Fig. 4. The vacuum stays in a range of $1 - 3 \times 10^{-7}$ Torr at a pump head. No significant temperature-rise has been detected during the operation.

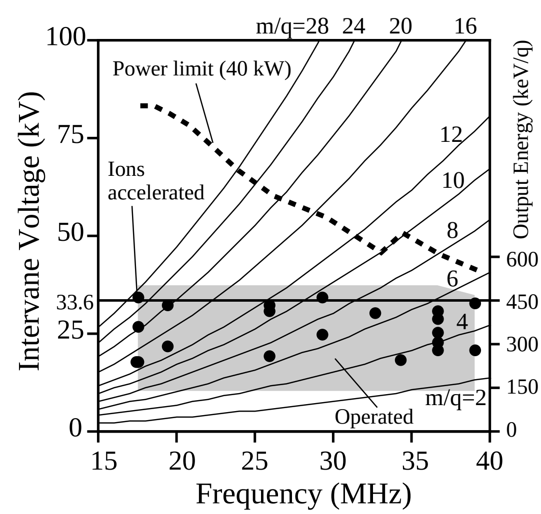

Fig. 4. Specification of the RFQ linac. The abscissa and the ordinate represent the resonant frequency and the intervane voltage, respectively. The output energy, proportional to the intervane voltage, is also indicated. The hatched area shows the region where the RFQ has ever been operated in the cw mode. The accelerated ions are indicated by closed 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), which is estimated by the measured shunt impedance of the resonator.

Acceleration Tests

Acceleration tests have been performed using ion beams from an 18-GHz ECRIS. The extracted beam from the ion source is focused by an Einzel lens and is bent by a bending magnet. The bending magnet also has a focusing function by the slant pole edges. The beam is focused again by a solenoid lens before entering the RFQ. There are two diagnostic boxes in the beam line. One is located between the bending magnet and the solenoid lens, which has a Faraday cup, two profile monitors, and two slits. The other is placed just after the RFQ, which has a profile monitor, a Faraday cup, two slits and an electrostatic deflector with a scanning wire probe.

The accelerated ions so far are $O^{3,4,5+}$, Ne^{4+}, $Ar^{2,3,6,8,9,11+}$, Kr^{9+}, Xe^{12+}, $Ta^{7,16,17+}$ at the frequencies of 17.7, 19.5, 26.1, 29.5, 32.8, 34.4, 36.8 and 39.2 MHz in the range of the intervane voltage of 17 - 35 kV. They are indicated by closed circles in Fig. 4. The maximum transmission efficiency, defined by the ratio of the beam current in the two Faraday cups, was 88 % with the beam intensity of 120 eμA.

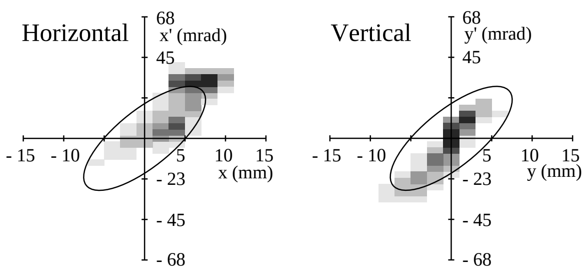

Fig. 5. Emittance of the input beam of Ar^{8+} extracted from the ECRIS at 8.5 kV, measured at 1400 mm upstream of the RFQ. The transmission efficiency was 87 %. The ellipse indicates the emittance assumed in the vane design (145 π mm•mrad).

The emittance of the input and the output beam was measured by the profile monitors along with the slits[5]. The input beam emittance from the ion source is 150 - 300 π mm•mrad, which decreases as the extraction voltage and the charge states of the ion increase. An example of the measured results is shown in Fig. 5. On the other hand, the output beam emittance is almost independent of the acceleration condition and is in agreement with the PARMTEQ simulation.

The energy distribution of the output beam was measured by the electrostatic deflector (40 mm in gap and 200 mm in length) placed downstream of the RFQ along with the scanning wire probe. The beam energy was deduced from the beam position measured by the probe, and the voltage applied to the deflector. As shown in Fig. 6, the output energy decreases as the intervane voltage is reduced, which is well reproduced by the simulation. The energy spread of the output beam was also measured by the same device. The result is 2-3% at FWHM and is consistent with the PARMTEQ simulation.

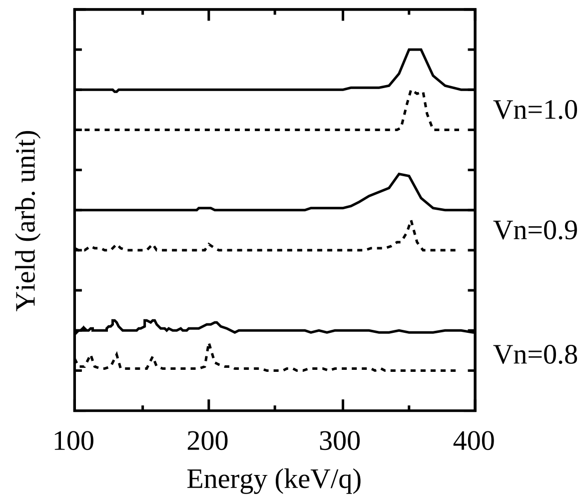

Fig. 6. Measured energy distribution (solid curves) and the PARMTEQ simulation (dashed curves). This measurement was done at the frequency of 17.64 MHz using Ar^{2+} beam. The corresponding output energy is 350 keV/q. The numbers represented by Vn indicate the ratios of the intervane voltage to the standard value of 26.1 kV.

Outlook

The new injector has been moved to the RILAC beam line in August 1996. Acceleration tests of the RILAC with the new injector will be completed by the end of this year.

The maximum extraction voltage of the 18-GHz ECRIS will be raised from 10 kV to 20 kV in the near future. New vanes are under fabrication so that the RFQ can accept the upgraded beams.

Acknowledgments

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