2p2-2

DEVELOPMENT OF A VARIABLE-FREQUENCY RFQ LINAC FOR THE RILAC

Osamu KAMIGAITO, Akira GOTO, Yoshitoshi MIYAZAWA, Toshiya CHIBA, Masatake HEMMI, Shigeo KOHARA, Masayuki KASE, Yuri BATYGIN, and Yasushige YANO

The Institute of Physical and Chemical Research (RIKEN)
Wako-shi, Saitama 351-01, Japan

Abstract

Development of a variable-frequency RFQ linac which will be used for a new injector for the RIKEN heavy-ion linac (RILAC) is under progress. The RFQ will accelerate ions with mass-to-charge ratios of 6 to 27 at up to 450 keV per charge by varying its operational frequency from 17.7 to 39.2 MHz. The RFQ resonator has a folded-coaxial structure and the resonant frequency is changed by a movable shorting plate. After low- and high power tests of the real RFQ structure, the acceleration tests have been performed using Argon and Oxygen beams at the frequencies of 17.7, 26.1, 34.4, and 39.2 MHz. The maximum transmission efficiency obtained from the first tests was 85 %.

1. Introduction

A new injector for the RIKEN heavy ion linac (RILAC)[1] has been developed, which consists of an 18GHz-ECRIS and a variable-frequency RFQ linac, in order to meet the growing demand for more intensity of heavy ion beams. As for the RFQ linac, a real structure has recently been constructed based on the study of the rf characteristics using a half-scale model. In this paper we describe recent results obtained from various tests as well as the outline of the RFQ resonator.

2. RFQ resonator

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

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. A stem suspended from the ceiling plate is in electric contact with the rectangular tube. A shorting plate placed around the stem can be moved vertically, which varies the resonant frequency. Radio-frequency power is capacitively fed through the side wall. A capacitive tuner is set on the other side and two capacitive pick-up monitors are on the base plate.

In addition to the equipment described above, a detachable stem is installed underneath the conductor tube. This stem is, however, pulled in only when high-frequency operation is required, and is in electric contact with both the conductor tube and the base plate while it is detached below the base plate in low-frequency operations. Because at installation, the rf electric current is shared by the detachable stem and the upper stem, the power consumption is expected to be less than that when only the upper stem is used.[3]

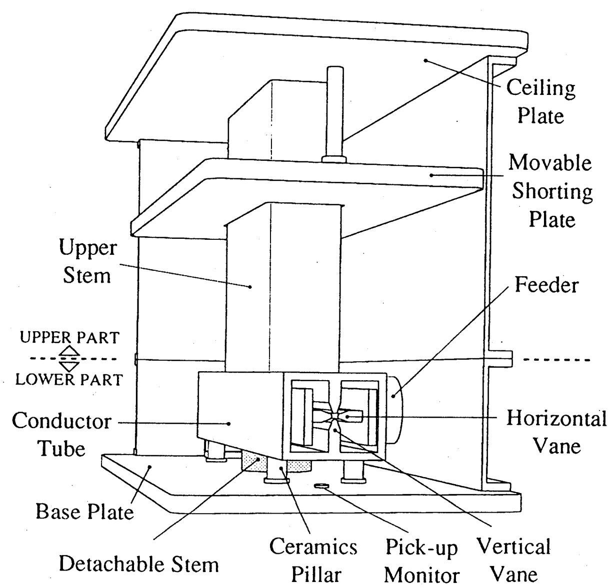

Figure 1. Schematic drawing of the RFQ resonator.

The inner volume of the resonator is about 1700 mm (length) × 700 mm (width) × 1000 mm (height). The resonator is separable into upper and lower parts, as shown in Fig. 1. The horizontal vanes and the rectangular tube with the vertical vanes are rigidly fixed inside 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 cooling pipes are placed by taking the result of the heat analysis into account. Cooling 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 supplied through the inside of the upper stem. The total water flow is 155 l/min of 7 atm.

Two turbo-molecular pumps (1500 l/s) are fixed on both sides of the resonator.

The vanes have been three-dimensionally machined within the accuracy of ±50 μm. The vane parameters have been modified from the output values of the PARMTEQ program because decrease of the transmission efficiency has been observed by a numerical simulation.[4]

3. Recent results

3.1 Low power tests

The resonant frequencies, the Q-values and the shunt impedances were measured in the same manner as in our previous paper.[2] Figure 2 shows the measured resonant frequency along with the values calculated by the MAFIA program. The horizontal axis represents the gap distance between the top surface of the conductor tube and the bottom surface of the shorting plate. The resonant frequency varies from 17.7 to 39.2 MHz by changing the position of the shorting plate by a stroke of 790 mm.

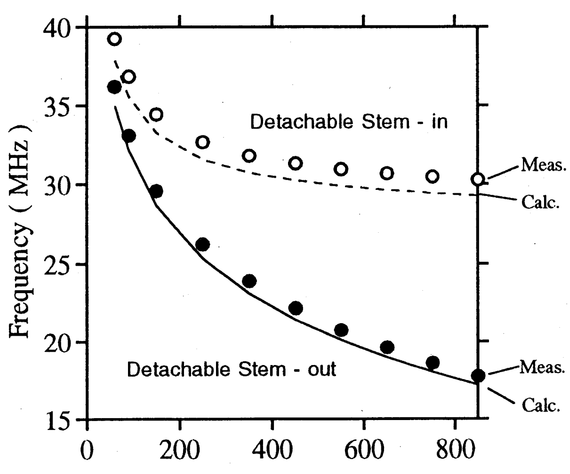

Figure 2. Measured resonant frequency along with the MAFIA calculations. The closed circles and the solid curve represent the measured and the calculated values, respectively, when the detachable stem is out of the resonator. The open circles and the dashed curve represent the measured and the calculated values, respectively, when the stem is in the resonator.

Figure 3 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 expected, above 30 MHz the measured Q-values and shunt impedances with the detachable stem installed are larger than those without the detachable stem. 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 designed intervane voltage of 33.6 kV in the cw operation.

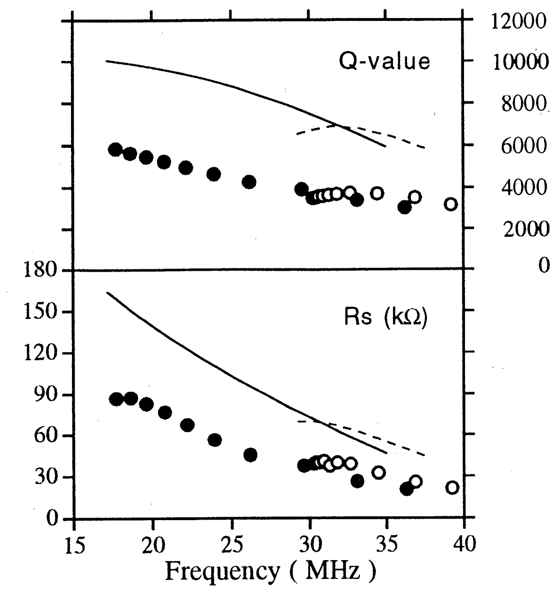

Figure 3. Measured Q-values and the shunt impedances along with the MAFIA calculations. The data of symbols and curves are obtained under the same conditions as in Fig. 2.

3.2 High power tests

The rf power source with an Eimac 4CW50000E has a cw power of 40 kW at maximum between 16.9 MHz and 40 MHz.

As a result of the high power tests, the following results have been obtained: [1] The RFQ can be stably operated when the intervane voltage is between 20 kV and 30 kV. The vacuum stays in a range of 1 - 3 $\times 10^{-7}$ Torr at a pump head. No temperature rise has been detected during the operation. [2] Emissions of blue-white glow are observed on the ceramic pillars below the intervane voltage of 15 kV. [3] Emissions of red-white light are observed above the intervane voltage of 35 kV.

The reasons of [2] and [3] described above are considered to be the multipactoring on the ceramics pillars and the heating due to the dielectric losses around the metal screws fixing the pillars to the conductor tube, respectively. Alternative structure of the pillars are under fabrication so as to avoid these drawbacks.

3.3 Acceleration tests

Acceleration tests have been performed using beams from an 18GHz-ECRIS. Figure 4 shows the schematic drawing of the beam line. The extracted beam from the ion source is focused by Einzel lenses and are 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.[5] The diagnostic boxes contain Faraday cups, profile monitors, and slits. Three capacitive pick-up probes are used for the TOF measurement of the beam velocity.

The accelerated ions so far are Ar^{3+}, Ar^{6+}, Ar^{11+}, and O^{5+} at the frequencies of 17.7, 26.1, 34.4, and 39.2 MHz, respectively, at the intervane voltage of about 20 kV. The maximum transmission efficiency was 85 % with the beam intensity of 10 - 50 eμA. The velocity of the output beam is in agreement with the designed value within 1 %.

In these tests the emittance of the input beam was not measured. The measurement is in preparation. Acceleration tests with full-intensity beams from the ECRIS are also to be performed.

4. Summary

A variable-frequency RFQ which will be used for a new injector of the RIKEN heavy ion linac (RILAC) has been constructed. Acceleration tests have been performed using beams from the 18GHz-ECRIS after low- and high power tests of the resonator. The maximum transmission efficiency obtained from the first tests was 85 %.

Alternative shapes of the ceramic pillars are under fabrication so as to avoid the drawbacks observed in the high power tests. Measurements of the beam emittance and the acceleration tests with full-intensity beams from the ECRIS are in preparation.

5. Acknowledgment

The authors are grateful to Dr. N. Tokuda and Dr. S. Arai at INS for the usage of vane-cutting program as well as for the fruitful information about the vane design. The resonator was fabricated by Sumitomo Heavy Industries, Niihama Work, and the rf power source by Denki Kogyo.

6. References

1. M. Odera, Y. Chiba, T. Tonuma, M. Hemmi, Y. Miyazawa, Y. Inoue, T. Kambara, M. Kase, T. Kubo, and F. Yoshida, "Variable Frequency Heavy-Ion Linac, RILAC," Nucl. Instrum. and Methods, 227, 187 (1984).
2. O. Kamigaito, A. Goto, Y. Miyazawa, T. Chiba, M. Hemmi, M. Kase, and Y. Yano, "Design of a New Type of a Variable-Frequency Radio-Frequency Quadrupole Linac with a Folded-Coaxial Resonator," Jpn. J. Appl. Phys. 33 (1994) L537.
3. O. Kamigaito, A. Goto, Y. Miyazawa, T. Chiba, M. Hemmi, S. Kohara, M. Kase, and Y. Yano, "Improvement of Frequency Variability of the Folded-Coaxial Radio-Frequency Quadrupole Linac by Installing a Detachable Stem in Its Resonator," to be published in Jpn. J. Appl. Phys.
4. Y. Batygin, A. Goto, O. Kamigaito, and Y. Yano: RIKEN Accel. Progr. Rep. 28 (1994) p.172 and in this proceeding.
5. N. Inabe, M. Kase, O. Kamigaito, Y. Miyazawa, M. Hemmi, T. Chiba, A. Goto, Y. Batygin, and Y. Yano: RIKEN Accel. Progr. Rep. 28 (1994) p.166.

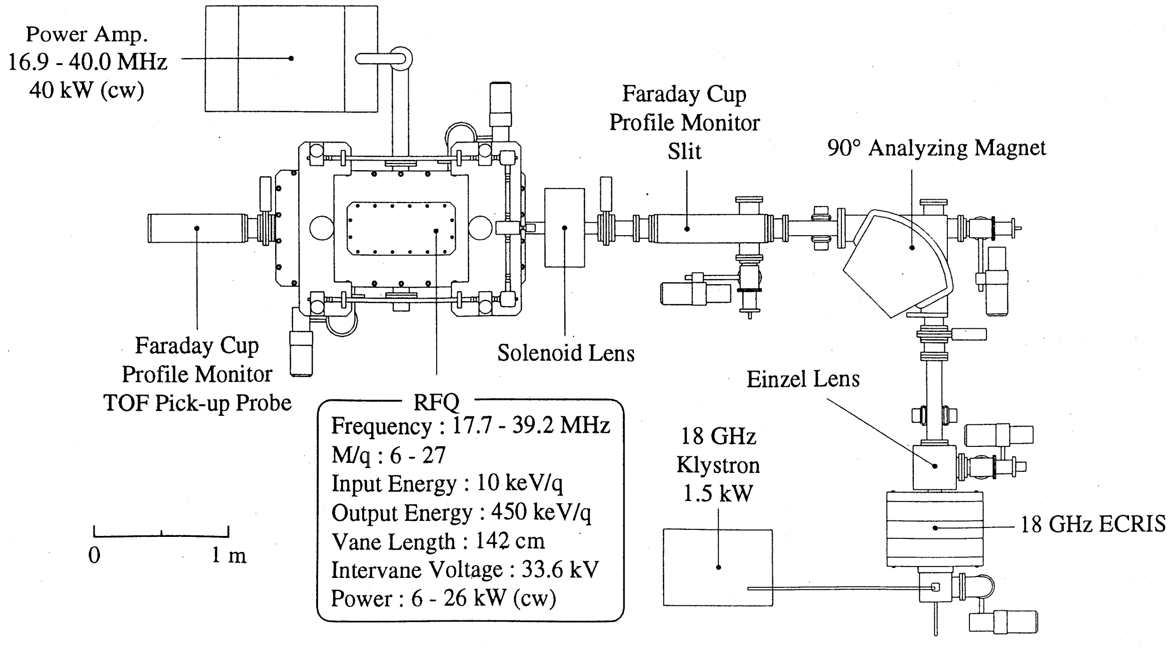

Figure 4. Schematic drawing of the beam line.