CONSTRUCTION OF A NEW PRE-INJECTOR SYSTEM FOR THE RILAC

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A new pre-injector system for the RIKEN heavy-ion linac (RILAC), which is used as an injector of the RIKEN Ring Cyclotron (RRC), has been completed in an attempt to increase beam intensities of heavy ions by one or two orders of magnitude. The system consists of an ECR ion source, a variable-frequency RFQ linac and a beam transport line between them. The performance tests of the whole system including beam acceleration test are being made successfully. It is planned to be installed on site next year.

1 Introduction

Recently we have started to do R&D's for the RI-beam factory project,[1] which aims to increase beam energies up to 400 MeV/u for light heavy-ions and 150 MeV/u for very heavy ions using a superconducting ring cyclotron[2] as a booster of the RIKEN Ring Cyclotron (RRC). One of the main purposes of the project is to produce radioactive-isotope beams and/or new isotopes in the whole range of nuclear masses up to uranium. In order to achieve the goal, it is indispensable to provide the RIKEN heavy-ion linac (RILAC),[3] the injector of the RRC, with much higher-intensity of heavy ions.

To meet the above demand, we have developed a new pre-injector system for the RILAC. The RILAC consists of six resonator tanks, each being of the Wideroe type and frequency tunable. The existing pre-injector system consists of an 8 GHz NEOMAFIOS and a 450 kV Cockcroft-Walton terminal. In the new pre-injector system is used a high-field, 18 GHz ECR ion source that is expected to have significantly high performance compared to the present 8 GHz NEOMAFIOS. A variable-frequency RFQ linac is adopted as an equivalent to the existing Cockcroft-Walton terminal, which is unable to accomodate such an 18 GHz ECR ion source that requires high electric power.

In this paper we describe the characteristics of the new pre-injector system and the status of its construction.

2 Description of the New System

Figure 1 shows a planned layout of the new pre-injector system toghether with the beam transport line from the existing one. The existing beam transport line is slightly modified from the present one for installation of the new system.
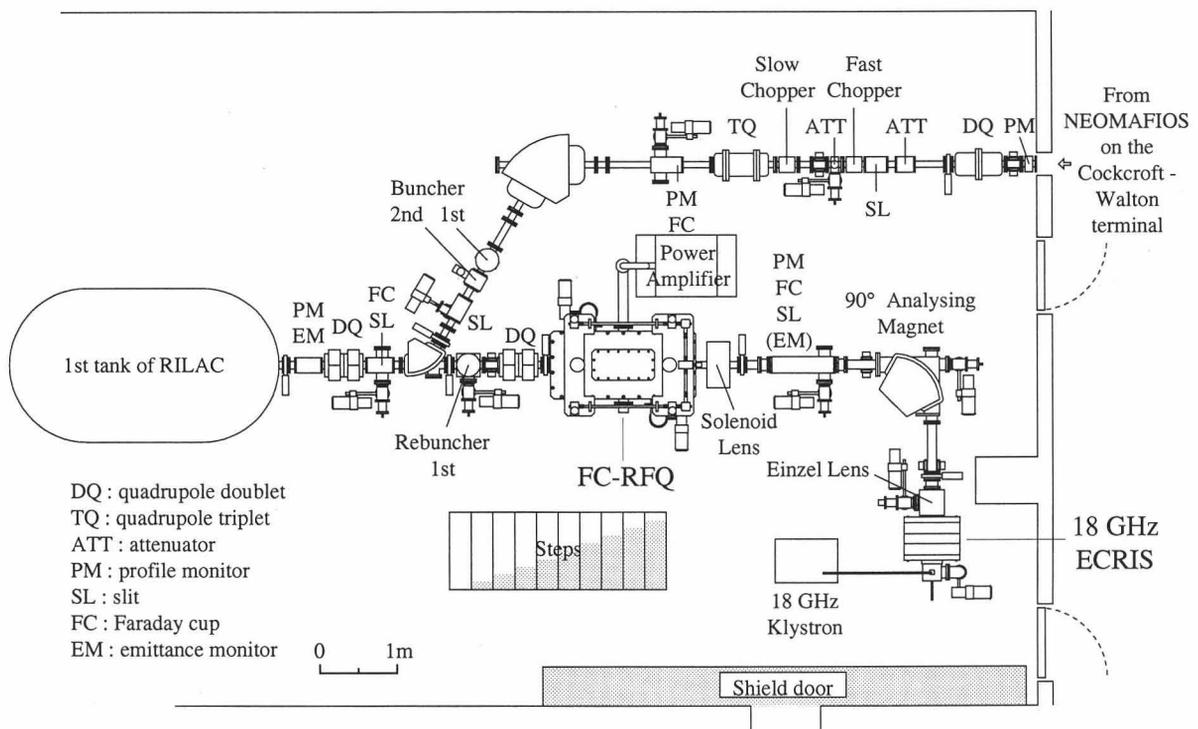

DQ : quadrupole doublet
TQ : quadrupole triplet
ATT : attenuator
PM : profile monitor
SL : slit
FC : Faraday cup
EM : emittance monitor

Figure 1 Planned layout of the new pre-injector system for the RILAC together with the beam transport line from the existing one.

2.1 18 GHz ECR Ion Source

Figure 2 illustrates a schematic drawing of the 18GHz ECR ion source.[4] The ECR ion source is of a single-stage type and operates at 18 GHz. The axial mirror field has peaks of 1.4 T (mirror ratio is 3.0) and the radial hexapole field is 1.4 T at the pole surface of 80 mm in diameter, both of which are high enough for the double-frequency operation. The axial mirror field is produced with a pair of solenoids, enclosed with an iron yoke, that are excited by two power supplies of 800 A. The power consumption of the solenoids is 140 kW and the required electric power for the power supplies is 210 kVA. The outer dimension of the yoke is about 700 mm in diameter and 550 mm in length. The radial field is produced with 36 segments of permanent magnets made of Nd-Fe-B, each segment 200 mm in length. The permanent magnet is protected from plasma heat by a plasma-chamber that is cooled by water of 20°C. The chamber is made of two copper cylindrical tubes that are welded to each other after the surface of the inner tube is carved to make conduits for coolant water. The thickness of the chamber is 3 mm. The temperature of the chamber is expected to rise up to 26°C at the maximum. The magnet is also protected from the heat of the solenoid coils by a similar copper cylindrical tube. A thin cylindrical tantalum tube of 0.1 mm in thickness is installed on the inside surface of the chamber for protection of the chamber from the plasma. RF of 18 GHz is fed by a Thomson TH 2463 klystron with the maximum output power of 1.5 kW. This RF power source is designed to operate in both cw and pulse modes. A rod of metal can be inserted axially for producing metallic ions. The plasma cathode method can be applied. The inside of the plasma chamber is evacuated with 500 and 150 l/s turbo-molecular pumps. Ions are extracted from an orifice of 10 mm in diameter with a maximum voltage of about 10 kV. The orifice is positioned at the end of the permanent magnet.

2.2 FC-RFQ Linac

The RFQ linac[5,6] is required to have the same function as that of the existing 450 kV Cockcroft-Walton terminal. It is designed to accelerate ions with a range of m/q = 6-27 up to 450 keV/q in the cw mode. The operational frequency should be varied between 18 MHz to around 40 MHz, which is one of the most important problems to be solved in the design of the RFQ linac.

To solve the problem, we have adopted a "folded coaxial" RFQ (FC-RFQ) structure.[5] The folded-coaxial structure allows the cavity to be tunable in a wide range of frequencies and to be compact even in the low frequncy region below 20 MHz. This structure can also enable the intervane voltage to be flat enough to obtain high beam-
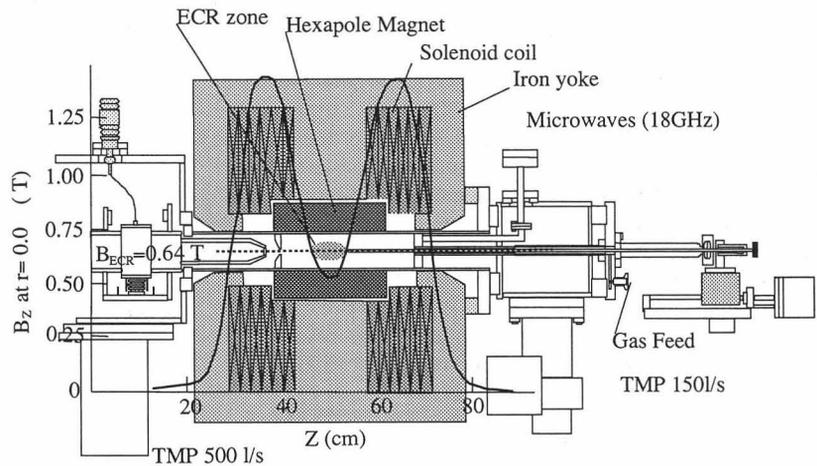

Figure 2 Cross sectional view of the RIKEN 18 GHz ECR ion source.

transmission efficiency. Figure 3 illustrates a schematic drawing of the RFQ linac. 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 that surround 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 pickup monitors are on the base plate. A detachable stem[7] is installed underneath the conductor tube and is in electric contact with both the conductor tube and the base plate, only when the linac operates in the high frequency region. With this method the
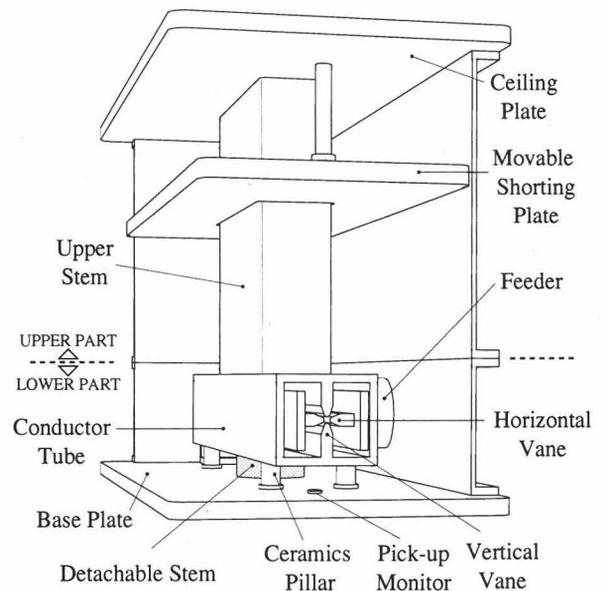

Figure 3 Schematic drawing of the FC-RFQ linac.

region of the resonant frequency can be expanded toward higher frequencies, and the power consumption is expected to be less than that when only the upper stem is used.

The length of the vanes is 1420 mm and the inner volume of the resonator is about 1700 mm (length) × 700 mm (width) × 1150 mm (height). The stroke of the shorting plate is 790 mm. The required maximum intervane voltage is 33.6 kV. RF power is fed by an amplifier with an Eimac 4CW50000E with a maximum output power of 40 kW between 16.9 MHz to 40 MHz. The total water flow for cooling is about 200 l/min of 7 atm and the temperature of water is 30 °C. The temperature of the vanes is expected to rise up to about 40 °C at the maximum. The resonator is evacuated with two turbo-molecular pumps of 1500 l/s.

2.3 Beam Transport Line

The beam transport line[8] between the ECR ion source and the FC-RFQ linac consists mainly of (from upstream) an Einzel lens, a 90° bending magnet, a beam diagnostic chamber and a solenoid magnet. In the design an ion beam is at first focused with the Einzel lens onto a spot of 10 mm in diameter at the symmetric position of the extraction orifice with respect to the lens. The beam is then analysed with the 90° bending magnet having slant edges and doubly focused at a point between the bending magnet and the solenoid magnet. The dispersion and magnification in the horizontal direction at this point are 2.2 cm/% and -0.98, respectively. From the values of dispersion and magnification, mass resolution m/Δm is about 200. The beam is finally matched to the FC-RFQ linac with the solenoid magnet.

The Einzel lens is of three-electrode type with different diameters: the diameter of the center electrode is 100 mm and that of the end electrodes is 74 mm. A voltage of about 15 kV at the maximum is required to be applied to the lens. The bending magnet has a curvature radius of 500 mm and a gap of 80 mm. The maximum magnetic field is 0.16 T. The angle of the slant edge is 28.7° at both the entrance and the exit. The solenoid magnet consists of coils and an iron yoke enclosing them. The inner diameter, outer diameter and length of the magnet are 90 mm, 610 mm and 310 mm, respectively. The maximum magnetic field is 0.63 T. Beam diagnostic devices such as a profile monitor, a Faraday cup and a pair of slits are set in the beam diagnostic chamber located between the bending magnet and the solenoid magnet. A beam emittance monitor can also be set in this chamber. The beam transport line is evacuated with two turbo-molecular pumps of 350 l/s.

3 Fabrication and Test

Fablication of the whole system was completed in the spring of 1995. We have made performance tests of the 18 GHz ECR ion source and the FC-RFQ linac as well as beam acceleration tests in the system. Details of the results are reported in refs. 4 and 6.

Ion beam intensities from the ECR ion source were measured for gaseous elements such as oxygen, argon and krypton with an extraction voltage of up to 15 kV (though a required maximum voltage is about 10 kV for delivering a beam to the FC-RFQ linac). Obtained beam intensities of Ar^{11+} and O^{7+} ions, for example, were 160 and 130 eμA, respectively, with an RF power of about 600 W and an extraction voltage of 15 kV. Typical gas pressures of the plasma chamber and the extraction stage were 1.0×10^{-6} and 9×10^{-7} Torr, respectively. Figure 4 shows the comparison between the measured beam intensities from the 18 GHz ECR ion source and those from NEOMAFIOS 8 GHz. It can be seen that the beam intensities from the 18 GHz ECR ion souce are higher than those from NEOMAFIOS 8 GHz by one or two orders of magnitude. It
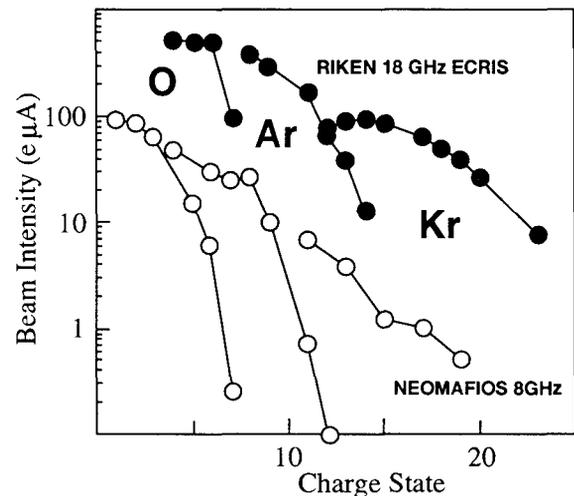
Figure 4 Comparison between beam intensities from the 18GHz ECR ions source and those from NEOMAFIOS 8 GHz.

is also noted that the beam intensity of, for example Ar^{11+} ions, from the 18 GHz ECR ion source was twice higher than that from CAPRICE 14.5 GHz when they are compared at the same RF power of 600 W. Pulse mode operation was also tested and significant afterglow effect was seen particularly for heavy ions like krypton and high charge states: the ratio was 4 for Kr^{20+} ions. A rod for metallic ions and a plasma cathode have not yet been tested. A thin cylindrical tube used in the plasma chamber, now made of tantalum, will be replaced by that made of aluminum and tested for increasing ion beam intensities.

The vanes of the FC-RFQ linac have been three-dimensionally machined and assembled within the accuracy of ± 50 μm, the value meeting the requirement for good beam transmission.[9] The surface of the vanes were polished with electrochemical buffing within a flatness of less than 1 μm. Figure 5 shows the measured resonant frequencies and Fig. 6 shows the measured Q-values and shunt impedances. The MAFIA-calculation curves are also shown in the both figures. The resonant frequency was measured to vary from 17.7 MHz to 39.2 MHz. The measured Q-values and shunt impedances were about 60 % of the MAFIA calculations. From the shunt impedance measurement, the required
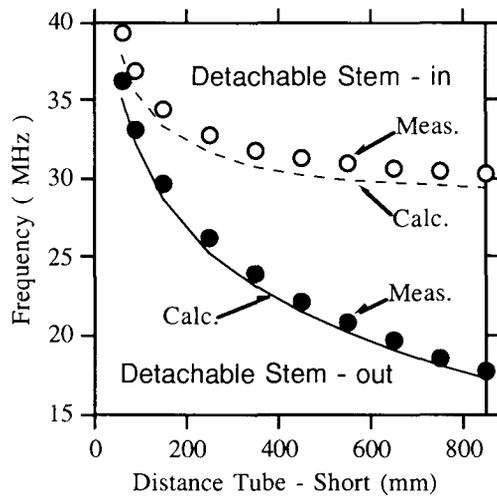
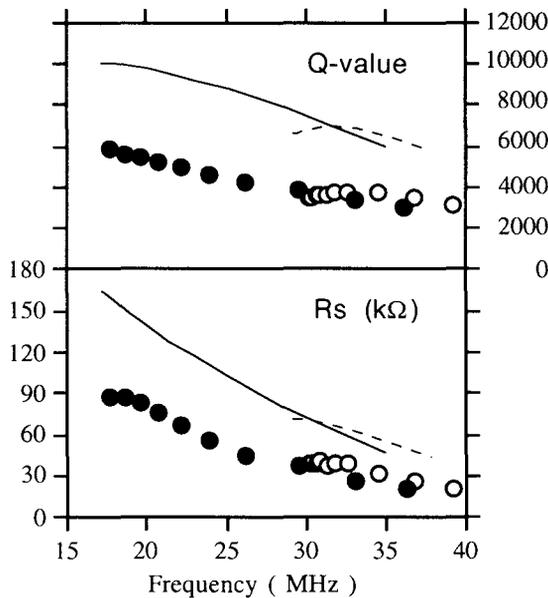Figure 5 Measured resonant frequencies along with the MAFIA calculations.

Figure 6 Measured Q-values and shunt impedances along with the MAFIA calculations. The meanings of symbols are the same as in Fig. 5.

maximum RF power was found to be 26 kW (cw). Typical gas pressure of the resonator was around 2×10^{-7} Torr. We have encountered a serious problem on the ceramic pillars on the base plate of the resonator; a multipactoring occurred on the pillars at an intervane voltage of below 15 kV, and heating due to dielectric losses in a local region of

the pillars occurred at an intervane voltage of above 35 kV. To fix this problem, ceramic pillars were redesigned and are being newly fabricated.

Beam acceleration tests have been performed for Ar^{3+}, Ar^{6+}, Ar^{11+} and O^{5+} ions at the frequencies of 17.7, 26.1, 34.4 and 39.2 MHz, respectively, at the intervane voltage of about 20 kV. The beam velocity after acceleration, which was measured by the TOF technique using three capacitive pickup probes, was in agreement with the designed value within 1 %. The beam transmission efficiency of 85 % at the maximum through the FC-RFQ linac was obtained from the first tests. Beam emittance has not yet been measured in this test.

4 Summary

A new pre-injector system for the RILAC was completed in the spring of 1995. The performance tests including beam acceleration showed that the beam intensity from the RILAC will increase by one or two orders of magnitude as expected. The system is planned to be installed on site next year. A beam rebuncher will also be installed at that time between the FC-RFQ linac and the RILAC.

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