RECENT DEVELOPMENTS OF THE FOLDED-COAXIAL RFQ FOR THE RIKEN HEAVY ION LINAC

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Abstract

The beam intensity available with the RIKEN heavy-ion linac (RILAC) has remarkably increased since the installation of a new injector in 1996, which consists of an 18-GHz ECR ion source and a variable-frequency RFQ based on a folded-coaxial resonator. Since August 1997, the maximum extraction voltage of the ECR ion source has been raised from 10 kV to 20 kV in order to upgrade the intensity further. The RFQ vanes were re-designed and replaced at the same time. Now the intensity has increased by about one or two orders of magnitude compared with those formerly available with the Cockcroft-Walton injector. The maximum power of the beam extracted from the RILAC and that from the ring cyclotron have reached 560 W and 2 kW, respectively. Another important result we have obtained is that the transmission efficiency through the RILAC is much improved by use of a prebuncher placed before the RFQ. Operational experiences of the RFQ as well as recent developments are described in this paper.

1 INTRODUCTION

As already reported[1], the new injector consisting of an 18-GHz ECR ion source (ECRIS) and a variable-frequency RFQ based on a folded-coaxial resonator has been working in the RIKEN heavy ion linac (RILAC) since August 1996. Figure 1 shows the RFQ along with the six tanks of the RILAC. Acceleration tests of the RILAC and the ring cyclotron (RRC) have been carried out continually using the beams from the new injector since the installation.

The beam intensity has remarkably increased owing to the high performance of the 18-GHz ECRIS[2]. In December 1996, we achieved the beam current of 1 pμA from the RRC for the first time using $^{36}Ar^{5+}$ beam supplied with the new injector.

One of the advantages of the new injector is that highly charged ions are readily generated with the ECRIS. The charge stripper between the RILAC and the RRC has become unnecessary for low-energy beams of medium-heavy ions such as Argon, so that the stability of the beam has been improved.

However, the extraction voltage of the ECRIS was quite low for the highly charged ions, because the maximum voltage was initially chosen to be 10 kV. The voltage was, for example, only 3 kV in the beam test mentioned above. This low voltage caused bad effects both on the intensity and the emittance of the extracted beams.

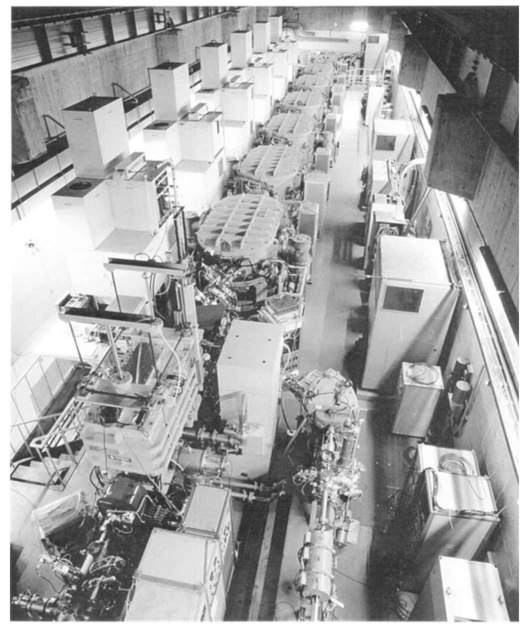

Figure 1: The RILAC and the RFQ seen from the upstream.

2 RECENT DEVELOPMENTS

2.1 New Vanes

Since August 1997, the maximum extraction voltage of the ECRIS has been raised to 20 kV in order to upgrade the beam intensity further. The RFQ vanes were re-designed and have been replaced.

The length of the initial sections of the vanes has increased, because the velocity of the input beam to the RFQ has become higher by about 40%. In order to keep the vane length less than the inner length of the resonator, we have raised the intervane voltage by about 5% and reduced the total number of the cells from 78 to 72. The mean aperture (r_0) have been slightly increased to reduce the capacitance between the vanes. All the parameters have been optimized by using the PARMTEQ code.

The vane parameters are listed in Table 1. Although the length has increased by 8%, the change of the frequency-

Table 1: Main Parameters of the RFQ

	~ 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
Beam margin	1.7	1.6
Focusing strength (B)	6.8	6.8
Max. defocusing strength	-0.30	-0.30
Final synchronous phase	-25°	-30°

range could be made very small. The vanes were three-dimensionally machined within the accuracy of ±50 μm and aligned within the same accuracy.

2.2 Transmission Efficiency

At the same time of the replacement of the vanes, an additional Faraday cup was installed just after the RFQ, as shown in Fig. 2, for the measurement of the transmission efficiency through the RFQ alone. The efficiency is defined by the ratio of the measured beam currents with the two Faraday cups (FC-R1 and FC-R2) shown in Fig. 2.

The maximum efficiency ever achieved is 92 %, being good enough compared with the calculated value of 94 %. The typical efficiency is about 80 to 90%, which depends on the input beam emittance varying with respect to the ion species and the extraction voltage.

One of the problems annoying us is that the efficiency up to the entrance of the RILAC is not so good as expected. Although the best efficiency is 80%, only 50 to 70% of the beam entering the first Faraday cup (FC-R1) is usually transported to the entrance of the RILAC. This means that some portion of the beam is lost in the matching section between the RFQ and the RILAC.

The RFQ can accept a beam having an emittance larger

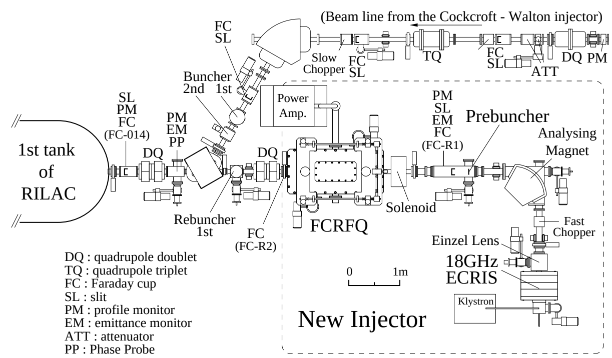

Figure 2: Schematic drawing of the new injector.

than the designed value of 145π mm•mrad, because the beam margin is large as shown in Table 1. However, the beam size exceeds the aperture diameter of the rebuncher when the input beam emittance is larger than the designed value or the beam ellipse does not match the designed ellipse. The aperture diameter of the rebuncher has been therefore enlarged from 40 mm to 50 mm, which does not help us so much. Additional devices such as quadrupole magnets is needed in the LEBT section to achieve more effective beam-transport.

2.3 A Prebuncher for the RFQ

As shown in Fig. 2, a prebuncher has been used in the LEBT section since the new injector was installed in the RILAC beam line. Its electrode consists of two mesh plates made of copper with a gap distance of 5 mm. A transformer is employed in the feeder line so that the termination register of 200 Ω matches the standard impedance of 50 Ω. The rf-power is supplied with a wide-band amplifier which transmits the maximum power of 1 kW in the frequency range from 5.5 MHz to 40 MHz.

This system was originally introduced to generate "single-bunch" beams by applying sub-harmonic (1/3 - 1/5 of the fundamental frequency) rf-voltage to the mesh electrode while a fast-chopper placed in the LEBT section sweeps the main part of the extracted beam from the ion source, based on the same method already established in the injection line of the AVF cyclotron[3]. It has been found that this method also works well in the RILAC.

On the other hand it has been reported elsewhere that the longitudinal emittance can be reduced by using the prebuncher with the fundamental frequency. We examined this effect by measuring the transmission efficiency through the RILAC, using Argon and Xenon beams from the new injector. In the test, the effect of the second and third harmonic components was also studied by adding these components to the fundamental rf-voltage.

A result measured with Ar^{5+} beam at the frequency of 18.8 MHz is shown in Table 2. As shown there, the transmission efficiency through the RILAC was much improved when the prebuncher was used, while that through the RFQ did not change so much. This result qualitatively agrees with the PARMTEQ simulation,

Table 2: Effect of the prebuncher on the transmission.

prebun.	FC-R1	FC-R2	FC-014*	FC-A02**
No Use	23.0μA (100%)	20.1μA (87%)	15.9μA (69%)	8.0μA (35%)
1f	23.0μA (100%)	20.1μA (87%)	16.9μA (73%)	12.1μA (53%)
1f - 3f	23.0μA (100%)	21.0μA (91%)	16.9μA (73%)	13.0μA (57%)

*The Faraday cup placed at the entrance of the RILAC (shown in Fig. 2).

**The Faraday cup placed at the exit of the analyzing magnet after the RILAC.

which shows little effect on the transmission efficiency through the RFQ but great reductions of longitudinal emittance of the accelerated beam.

It was hard to observe the effect of the higher harmonic components because the gap distance of the mesh electrode was too wide and the impedance-matching of the transformer in the high frequency region was not so good. Systematic study of the higher components as well as measurements of the longitudinal emittance are under preparation.

3 PRESENT STATUS AND OUTLOOK

The beam intensity from the ECRIS has increased by a few times since the extraction voltage was raised. The maximum current ever extracted from the RRC is 2 pμA for Argon and 200 pnA for Xenon. Comparing these values with the beam current formerly available with the Cockcroft-Walton injector, the intensity of Argon beams has increased by one order of magnitude. For Xenon beams, the intensity has become larger by two orders. The ions accelerated so far are summarized in Fig. 3.

Figure 4 shows the maximum transmission efficiency ever achieved up to the exit of the RILAC. It has become 1.5 times larger than that using the Cockcroft-Walton injector. Typical transmission efficiency from the ECRIS to the exit of the RRC is 10 to 20 %. The maximum beam power ever provided with the RRC is 2 kW (2 pμA of Argon at 24 MeV/u) and that with the RILAC is 560 W (13 pμA of Oxygen at 2.5 MeV/u). Considering the high beam power, the transmission should be further improved.

We are planning to construct an improved prebuncher system for the RFQ, which can generate "saw-tooth" wave-form. The design is under progress.

4 ACKNOWLEDGEMENTS

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5 REFERENCES

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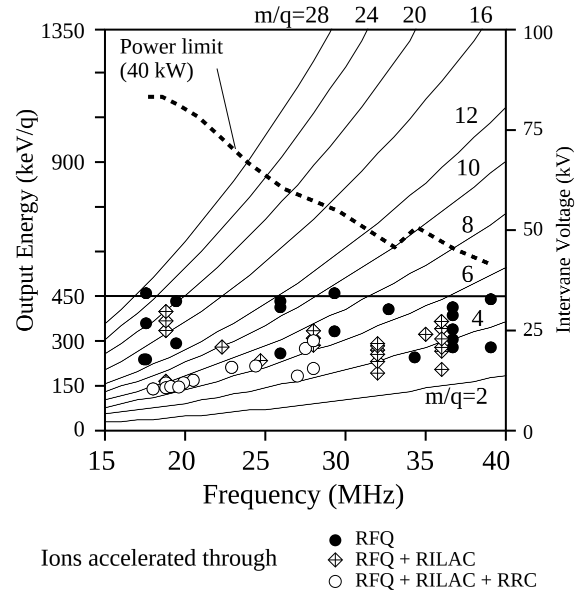

Figure 3: Performance of the RFQ linac. The abscissa and the ordinate represent the resonant frequency and the output energy, respectively. The intervane voltage, which is proportional to the output energy, is also indicated. The ions accelerated until July 1998 are indicated by the closed circles, diamonds, and 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 amplifier (40 kW).

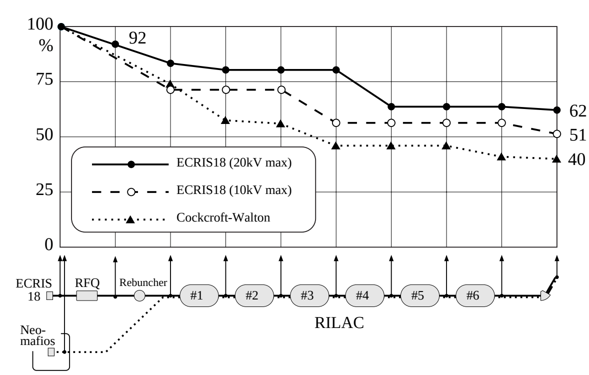

Figure 4: The best transmission efficiency ever achieved through the RILAC.