DEVELOPMENT OF AN ECR ION SOURCE AT CNS

Y. Ohshiro, S. Kubono, S. Watanabe, S. Yamaka,

Center for Nuclear Study, Graduate School of Science,
the University of Tokyo (CNS), 351-0198, Japan

Abstract

A 14-GHz ECR ion source (named HyperECR) was developed in early 90’s at university of Tokyo. The HyperECR was moved to RIKEN and installed for the AVF cyclotron for nuclear astrophysics project at CNS. To switch a RIKEN 10-GHz ECR and the HyperECR, a rotatable bending magnet was installed. To reduce the losses of the beams transported from the HyperECR to the cyclotron, the design parameters of this system have been optimized by an optical matching simulation. Thus far, the transmission efficiency of 29% has been achieved. Moreover, the beam extraction method was modified by replacing an ion-decelerator. Preliminary experiments show an increase of the beam intensities of $^{14}N^{5+}$ and $^{14}N^{6+}$. In this paper, the progress of the HyperECR and the injection system to the AVF cyclotron are described.

INTRODUCTION

In 1999, the HyperECR was moved from the old Tanashi campus to the RIKEN site. A new beam line and a rotatable bending magnet for switching the 10-GHz ECR and the HyperECR were constructed in February 25, 2002. Since then, the HyperECR and the 10-GHz ECR have been operating to deliver the beams of gaseous [1] and metallic elements alternatively. Extracted beams from the AVF cyclotron are transported to either CRIB [2] or the RRC (RIKEN Ring Cyclotron). When one source supplies the beam to the AVF cyclotron, the other may be used for development of new beams. A variety of ions of highly charge states are delivered by the HyperECR and used for nuclear and biological experiments.

BEAM TRANSPORT SYSTEM

The HyperECR was installed in the ion source room for the AVF cyclotron. A schematic drawing of the complete setup is shown in Fig. 1 and a list of the elements with their specifications is given in Table 1.

The beam intensities extracted from the HyperECR are known to increase almost linearly with an extraction voltage up to about 25 kV and with a little saturation above 20 kV. The newly constructed beam transport system has the maximum $B\rho$ of 118.5 kGcm, while the AVF cyclotron accepts the ions with energy of about 10 keV due to its constant-orbit acceleration.

To reduce the beam losses through the transported from the ion source to the AVF cyclotron, we have done three improvements as follows: 1) The HyperECR was set properly to an analyzing magnet so that the extraction point of the ion source is exactly on the object point of the analyzing magnet.

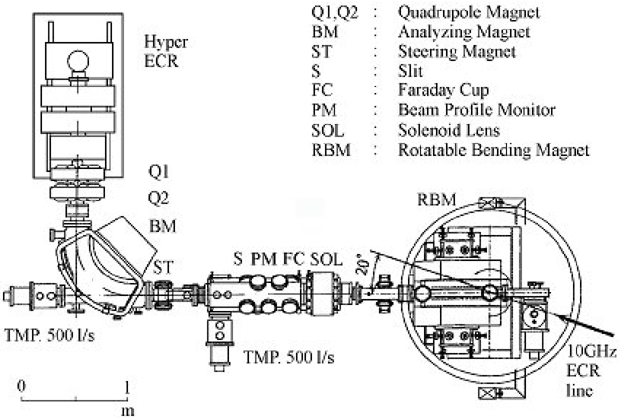

Fig. 1: Top view of the HyperECR and the beam transport line to the rotatable bending magnet. The beam line was set with a deviation angle of 160 degrees from that of the 10-GHz ECR.

2) A pair of quadrupole magnets was set between the source and the analyzing magnet for focusing of emitted beams from the ion source. 3) As for the analyzer, the magnetic field uniformity was at ±0.1% to make the beam size small on a focal plane.

The analyzing magnet is a C-type magnet that has a vacuum chamber with an exhaust port and a monitor port. To make a magnetic field distribution uniform, a partialness gap of 2 mm was inserted both for the magnetic poles, and two hills were made at the edge of the magnetic pole, where one is 2 mm x 15 mm and other 2 mm x 22 mm, as seen in Fig. 2.

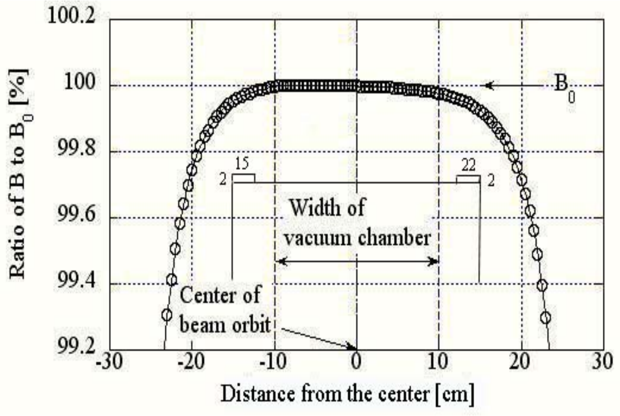

Fig. 2: A radial magnetic field distribution.

The measured magnetic field distribution is shown in Fig. 2. As a result, the uniformity of ±0.1%, $(B_0-B)/B_0$, of the magnetic field distribution has been obtained within the width of ±10 cm along the extraction axis.

Moreover, the fringing magnetic field gradients of the entrance and the exit of the analyzing magnet were modified with the iron frames, respectively. This makes that the effective magnetic field boundary (EFB) is about 7 mm from the physical boundary.

Table 1: Summary of the specifications of the beam analyzing system and the beam transport.

Drift space to analyzing magnet	108.5 cm
Quadrupole magnets	
field gradient	0.24 kG/cm at 20 A
pole length	10 cm
bore radius	6.05 cm
Analyzing magnet	
bending angle	90 degrees
bending radius	50 cm
pole gap	8 cm
maximum field strength	2.37 kG at 220 A
edge angle	29.6 degrees
magnification	1
Drift space to the image slits	108.5 cm
Solenoid magnet	
bore length	20 cm
bore radius	6.2 cm
maximum field strength	2.5 kG at 100 A
Rotatable bending magnet	
bending angle	90 degrees
bending radius	50 cm
pole gap	8 cm
maximum field strength	1.5 kG at 102 A
edge angle	29.6 degrees
magnification	1

HyperECR

The HyperECR ion source was developed in early ‘90s and used for atomic physics experiments at the CNS. We succeeded in producing intense beams of highly charged ions (e.g. 300 eμA of $^{14}N^{5+}$ and 60 eμA of $^{14}N^{6+}$) from this source [3].

The schematic drawing of this ion source is shown in Fig. 3 together with the mirror field distribution used for $^{12}C^{5+}$ and $^{14}N^{6+}$ production. In this case, the exiting currents are 450 A and 550 A for two solenoid coils, respectively. The mirror ratio is about 2.7 (B_{max} ~11 kG and B_{min} ~4 kG). A length of the ECR zone is about 7 cm. Electrical power consumption was about 40 kW. To confine the plasma radially, we used a sextuple magnet made of Nd-Fe-B permanent magnets. The field strength at the surface of the magnets is about 10.6 kG.

We investigated the dependence of the beam intensity on the extraction voltage. In case of $^{14}N^{5+}$ and $^{14}N^{6+}$, the beam intensity extracted at 20 kV was found to increase nearly 3 times as that at 10 kV.

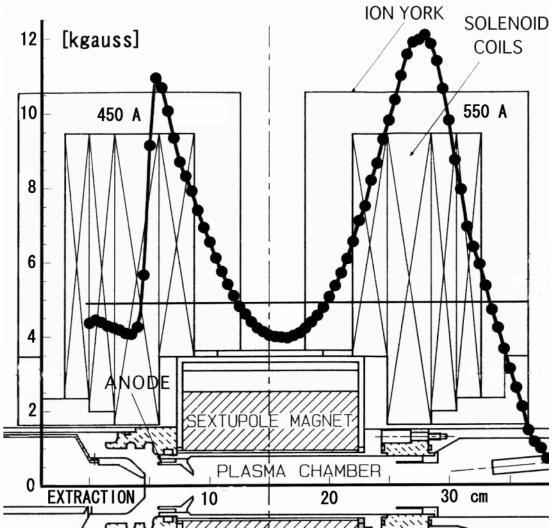

Fig. 3: The schematic drawing of the HyperECR together with the mirror field distribution used for $^{12}C^{5+}$ and $^{14}N^{6+}$ production.

ION-DECELERATOR

The ion beams were extracted by the electrostatic voltage which was equivalent to injection voltage of 5 to 11 kV. For the extraction, we replaced an extraction system from a present electrode by an ion-decelerator in order to increase the extraction voltage up to 20 kV, but without changing the injection voltage.

Figure 4 shows the new ion-decelerator, where the electrodes are arranged in the order of a negative electrode and a ground one from right-hand side. This unit is set near the anode electrode (see Fig. 3) with a gap of about 45 mm between the anode electrode and the negative one. Beams go through from right to left.

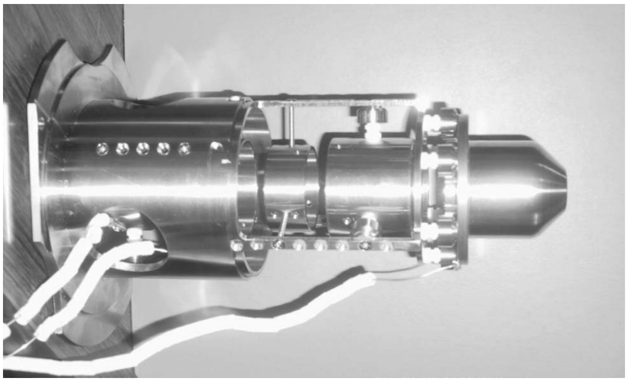

Fig. 4: The ion-decelerator unit set in an extraction chamber of the HyperECR.

We investigated the voltage dependence on the beam intensity at the negative electrode, while the anode electrode that was at 10 kV. In case of $^{14}N^{6+}$ and $^{14}N^{5+}$ ions, the maximum beam intensity was obtained at –5 kV on the negative electrode (total 15 kV extraction) for

$^{14}N^{6+}$, and –7 kV (total 17 kV one) for $^{14}N^{5+}$. Both ions, the beam intensity increased roughly by a factor of two.

BEAM TRANSMISSION EFFICIENCY TO THE AVF CYCROTRON

The beam transmission efficiencies from the HyperECR ion source to the AVF cyclotron were measured. A schematic diagram of the beam transport system is presented in Fig. 5.

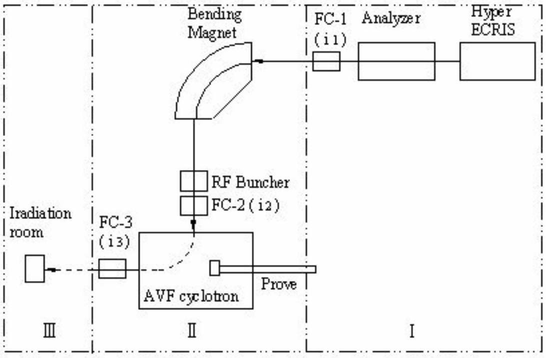

Fig. 5: Schematic side view of the beam transport system.

The ion beams from the ion source are transported horizontally (see I in the figure), and vertically injected into the cyclotron through the beam line that has the bending magnet (see II in the figure), a quadrupole quartet, five solenoid magnets, an axial hole in a pole of the cyclotron, and a spiral inflector [4]. An RF buncher is placed about 2 m above the center of the cyclotron, just in front of an upper magnetic yoke of the cyclotron.

We have studied the transmission efficiency, i_3/i_1, where i_3 is the extraction current at FC-3 and i_1 is the analyzed beam current at FC-1. Some results so far obtained are shown in Table 2. As shown in the table, the transmission efficiency achieved ranges 13 - 29%. The RF buncher increases the beam current by a factor of 3 - 5.

Table 2: Some results of the ion beams extracted from the AVF cyclotron.

Ion Species	Acceleration Energy [MeV/u]	Extracted beam current [eμA]	Transmission efficiency [%]
H^+	9.9	7.8	14
$^{12}C^{4+}$	7.0	5.3	19
$^{13}C^{4+}$	5.5	3.8	25
$^{14}N^{5+}$	7.0	4.3	13
$^{14}N^{6+}$	6.4	1.7	29
$^{20}Ne^{7+}$	6.3	3.0	25

For investigation of the beam transmission efficiency, a beam emittance was measured. The emittances in $^{14}N^{6+}$ acceleration of 29% of beam transmission were 115 and 89 πmmmrad in horizontal and vertical, respectively. In order to decide the design parameters, a beam optics calculation was performed by assuming 138 and 91 πmmmrad in both planes. These values are roughly in agreement with the measured values.

On the other hand, a beam energy spread has been improved by installation of a flattop acceleration system [5]. The beam transmission measurement with use of flattop acceleration will be made in the near future.

The design parameters of the beam injection line have been optimized by the optical matching simulation for the beam injection through the axial hole (hole lens) to the inflector entrance. Figure 6 shows the envelopes of the beam in both transverse planes.

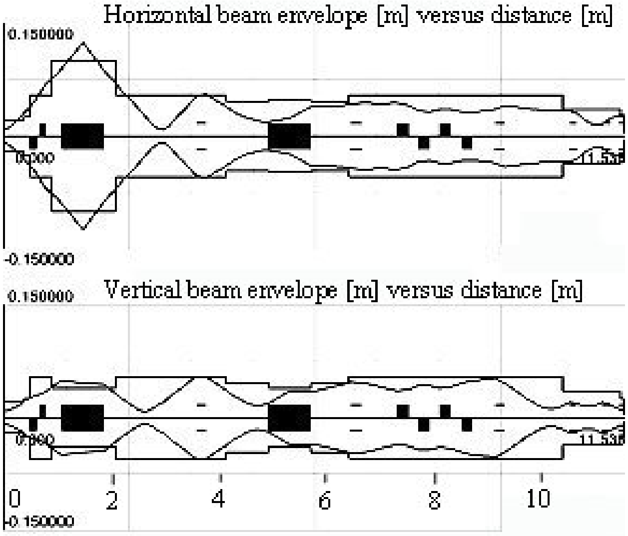

Fig. 6: Beam envelopes calculated in horizontal and vertical planes, respectively.

This calculated result is a solution with which about 95% beam from the ion source reaches the inflector of the cyclotron. However, the measurement shows about 70% beam loss near the center of the cyclotron. We are now studying the central region to get better transmission.

CONCLUSION

We had installed the HyperECR and the beam transport line in the AVF cyclotron at RIKEN. The beam transmission efficiency from the HyperECR line to the exit of the AVF cyclotron has been measured to be 13 - 29%. This will be improved further by making the beam emittance small at the Hyper ECR as well as by modifying the central region of the cyclotron.

REFERENCES

[1] Y. Ohshiro *et al.*, RIKEN Accel. Prog. Rep. 36 (2003) 279.
[2] Y. Yanagisawa *et al.*, RIKEN Accel. Prog. Rep. 34 (2001) 183.
[3] M. Sekiguchi *et al.*, INS-Rep.-993, July. 1993.
[4] N. Nakanishi, *et al.*, RIKEN Accel. Prog. Rep. 20 (1986) 188.
[5] S. Watanabe *et al.*, CNS-REP-48, Sept. 2002.