DEVELOPMENT OF THE RCNP CYCLOTRON CASCADE

K. Hatanaka, M. Fukuda, M. Kibayashi, S. Morinobu, K. Nagayama, H. Okamura, T. Saito, A. Tamii, H. Tamura, and T. Yorita

RCNP, Osaka University, 10-1 Mihogaoka, Ibaraki, Osaka 567-0047, Japan

Abstract

The RCNP AVF cyclotron has recently been upgraded to satisfy a variety of requests by users. A flat-top system was introduced to improve the beam quality and an 18 GHz ECR ion source was built to produce highly charged heavy ions beams. A new beam line was installed to diagnose the characteristics of the beam to be injected into the ring cyclotron as well as to bypass the ring cyclotron and .directly transport low energy beams from AVF to experimental halls. Power supplies of 13 trim coils and magnetic channels were renewed, since it became difficult to get electronic parts to repair them. The control system was replaces by a PC-based distributed system using network. Results of development along the upgrade project are described.

INTRODUCTION

The schematic layout of the RCNP cyclotron facility is shown in Fig. 1. The accelerator complex consists of an injector AVF cyclotron (K=140) and a ring cyclotron (K=400). It provides ultra-high quality beams as well as moderately high intensity beams for a wide range of researches in nuclear physics, fundamental physics, applications and interdisciplinary fields. Maximum energy of protons and heavy ions are 400 and 100A MeV, respectively. Sophisticated experimental apparatuses are equipped like a pair spectrometer, a neutron time of flight facility, a radioactive nuclei separator, a super-thermal Ultra Cold Neutron (UCN) source, a white neutron source and a RI production system for nuclear chemistry. Such ultra high resolution measurements as $\Delta E/E=5x10^{-5}$ are routinely performed with the Grand Raiden spectrometer by utilizing the dispersion matching technique. The UCN density was observed to be 10UCN/cc at the experimental port with the beam power of 400 W. The white neutron spectrum was calibrated and the flux was estimated to be 70 % of that obtained at LANS. Neutrons are used for the radiation effect studies on integrated circuits et al. User's demands on the beam characteristics are expanding rapidly,; ultra-high resolution, high intensity, a variety of heavy ions, and so on. Since there are no slits or collimators in the beam lines after the ring cyclotron, the beam quality on targets is determined by the characteristics of the beam from the AVF cyclotron. The injector upgrade program is in progress on these items [1];

1. a new acceleration system with a flat-top system.
2. an 18 GHz ECR ion source to produce highly charged heavy ions.
3. a polarized Li^{3+} ion source
4. a beam line to diagnose the beam characteristics from the AVF cyclotron as well as to deliver low energy beams to the experimental halls
5. power supplies of 13 trim coils and magnetic channels
6. renewal of the accelerator control system by a PC-based distributed system using network.

The structure and performance of the flat-top system is given somewhere in this proceedings [2].

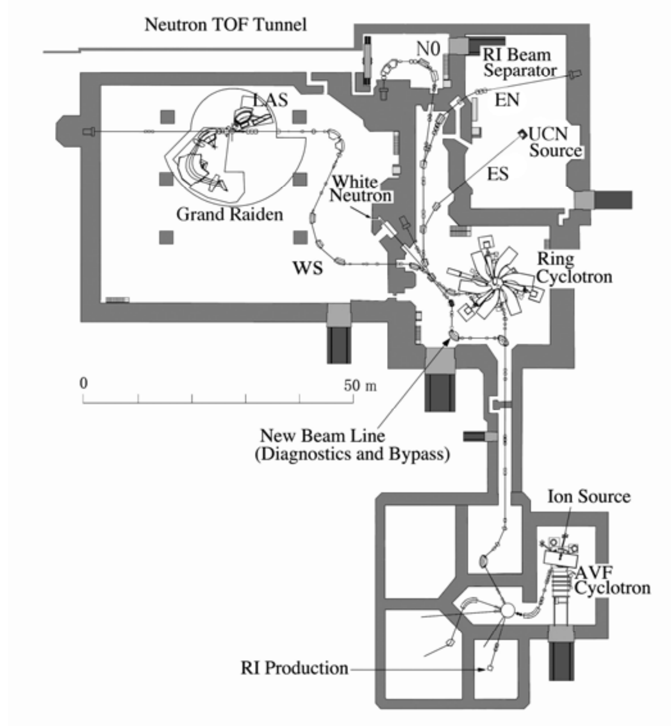

Figure 1: Layout of the RCNP cyclotron facility.

18 GHZ SUPERCONDUCTING ECR ION SOURCE

An 18 GHz superconducting ECR ion source was installed in order to increase beam currents and to extend the variety of ions, especially for highly charged heavy ions which can be accelerated by RCNP cyclotrons. The resonance conditions for acceleration of the AVF cyclotron are shown in Fig. 2. The production development of several ions beams and their acceleration by the AVF cyclotron has been performed since 2006.

Figure 3 shows the cross sectional view of the source. The source has been designed based on RAMSES [3] at RIKEN, but the inner diameter of the hexapole magnet and of the plasma chamber are extended to 90 and 80 mm, respectively, due to the experience of their development.

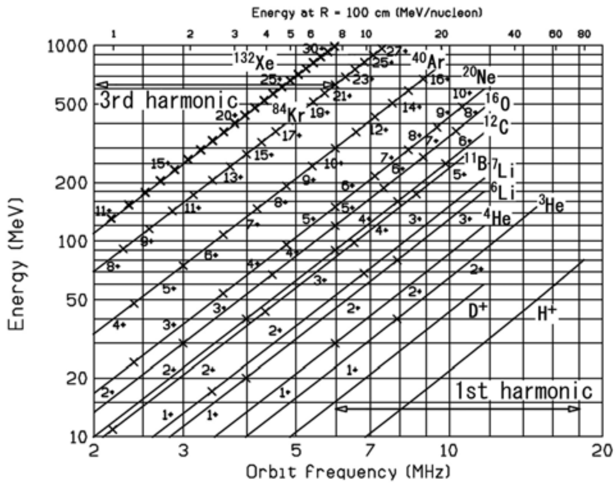

Figure 2: The resonance conditions for acceleration of the RCNP AVF cyclotron.

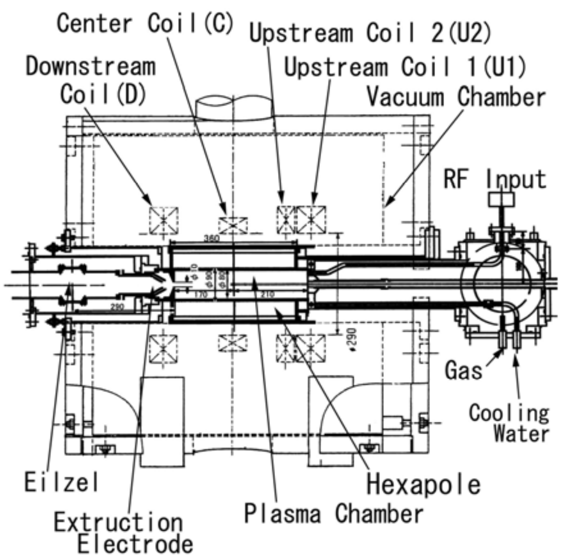

Figure 3: Cross sectional view of liquid-helium free 18 GHz superconducting ECR ion source.

The mirror magnetic field is produced with four liquid-helium-free superconducting coils which are cooled by two Gifford-McMahon refrigerators, and installed in a cryostat chamber covered by iron magnetic shields. Upstream coil 1 (U1) and downstream coil (D) are of the same size and excited in series by a common power supply. Central coil (C) and upstream coil 2 (U2) are excited by independent power supplies and then the mirror magnetic field distribution is controlled quite flexibly. Typical simulated (by TOSCA) magnetic field inductions created on the axis by each coil are shown in Fig. 4. Typical operating currents are 36.3 A, 36.9 A and 60.5 A for U1+D, C and U2 coil, respectively. The maximum current for any coil is 66A.

A permanent magnet hexapole is of Halbach type with 24 pieces of NEOMAX-44H material. On the stainless-steel plasma chamber inner diameter, the radial field strength is 1.0 T. The diameter and length of the plasma chamber are 8 cm and 38 cm, respectively. In order to improve the performances of the source, the insertion of a liner has been decided. Tests have been performed with two different thicknesses and materials (1 and 3.5 mm; pure aluminium and aluminium coated with Al_2O_3). In the latter case, it was difficult to get stable operation due to discharge or degassing from the liner.

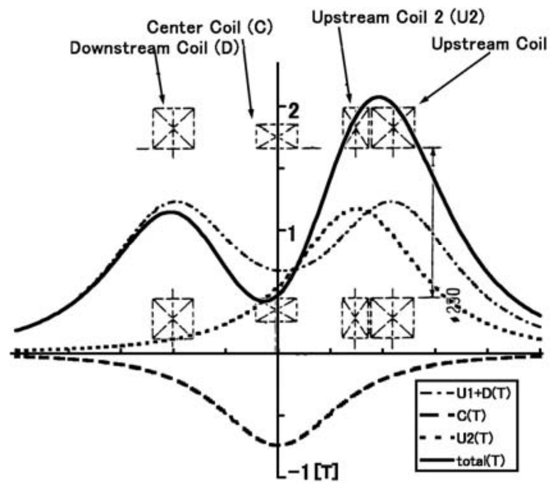

Figure 4: Simulated magnetic field distribution.

A bias probe is installed on the beam axis on the injection side. The maximum applicable voltage is -500 V relative to the plasma chamber and the probe position is variable between 120 and 220 mm from the centre of the C coil. The optimum position is located at 170-190 mm which corresponds to the position of the maximum mirror field. The extraction system is composed of two electrodes and can be moved along the beam axis. An einzel lens is placed at the downstream of the extraction electrode.

The ion beams extracted from the source are analysed by a dipole magnet (AM) and measured in a Faraday cup (FC) placed at the image focal point of the dipole. Figure 5 shows the typical charge state distribution of ^{86}Kr ion obtained when using oxygen as gas mixing. $^{86}Kr^{21+,\ 23+}$ ions were accelerated by the AVF cyclotron for the first time and were delivered to user's experiments.

In order to produce metallic boron ions, a test by MIVOC (Metal Ion from VOlatile Compounds) method [4] has been performed using o-carborane ($C_2B_{10}H_{12}$). Its vapor pressure is around 1-2 Torr at the room temperature. The stable flow of the vapor from o-carborane powder to the plasma chamber enables us to produce stable boron ion beam. The o-carborane is put in glass vessel directly connected to the plasma chamber via a buffer tank. Helium support gas is used as the mixing gas. Figure 6 shows the charge state distribution of boron ions. Oxygen ions in Fig.6 are likely as a result of degassing due to the wall heating. Different support gases have been tested to optimize $^{11}B^{5+}$ intensities. With oxygen, we were not able to produce $^{11}B^{5+}$; with hydrogen, the current was divided by three with respect to helium.

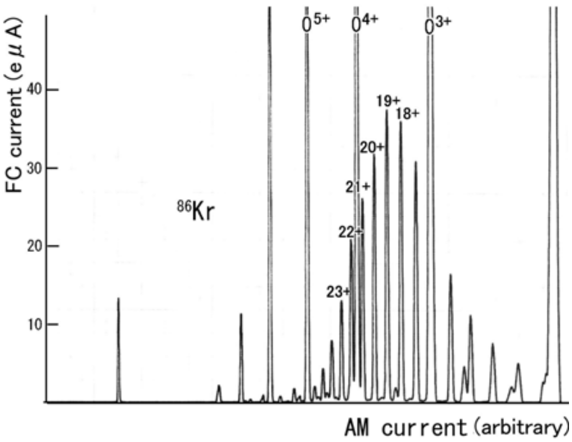

Figure 5: Charge state distribution of ^{86}Kr ions with 700W RF and oxygen mixing.

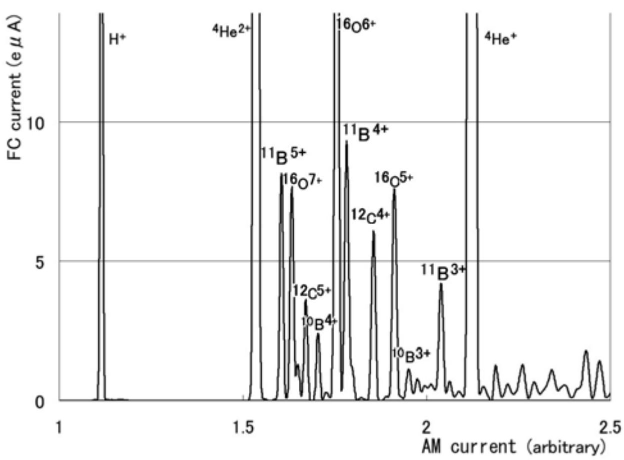

Figure 6: Charge state distribution of ^{11}B ion.

NEW BEAM LINE

A new beam line was installed to bypass the ring cyclotron and to directly deliver low energy and high intensity beams from the AVF cyclotron to the experimental halls where sophisticated apparatuses are available It is expected to increase research oppotunities at the cyclotron facility. The schematic layout of the beam line is shown in Fig. 7. In addition, the line from the "source point" in the figure to the "focus point" serves to diagnose the quality of the beam which is injected into the ring cyclotron. As mentioned above, the quality of the beam on targets from the ring cyclotron is primarily determined by the characteristics of the injected beam from the AVF cyclotron. However, there had been no available diagnostic devices to precisely measure its emittance and energy spread before injection. Two 90-degree dipole magnets have a bending radius of 1200 mm. They have round pole faces to reduce ion optical second order aberrations. The momentum dispersion of the analyzing section is designed to be 12.6 m. Parameters of the AVF cyclotron and the transfer beam line to the ring cyclotron can be optimized by referring to the measured beam characteristics.

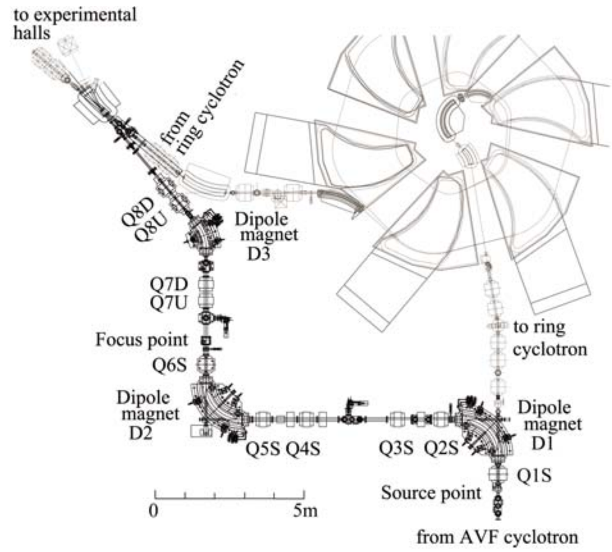

Figure 7: Schematic layout of the beam line to analyze the quality of the beam from the AVF cyclotron as well as to directly deliver low energy and high intensity beams to experimental halls of the ring cyclotron.

SUMMARY

The upgrade of the RCNP cyclotron cascade has been successfully started and is being continued. The beam quality and intensity of 300 MeV proton has been improved by the flat-top acceleration in the AVF cyclotron [2]. Developments are being performed to apply the system to other beams. An 18 GHz superconducting ECR ion source has been commissioned to increase the beam intensity of highly-charged heavy ions; 7.5 MeV/u ^{86}Kr^{23+} beam was delivered to experiments. A new beam line has been installed to diagnose the beam characteristics from the AVF cyclotron and helps to make it match to the acceptance of the ring cyclotron. It also makes 10-400 MeV protons and 1-100 MeV/u heavy ions available for a variety of researches in nuclear physics and fundamental physics as well as interdisciplinary studies.

REFERENCES

[1] K. Hatanaka et al., Proc. 17th Int'l Conf. on Cyclotrons and their Applications, Tokyo, Japan, 115 (2004)
[2] M. Fukuda, in this proceedings.
[3] T. Nakagawa, et al., Rev. of Scientific Instruments 75 (2004) 1394
[4] H. Koivisto et al., Nucl. Instr. And Meth. In Phys. Res., B117 (1996) 186