UPGRADE PROJECT OF THE RCNP AVF CYCLOTRON FACILITY

Kichiji Hatanaka, Takahisa Itahashi, Masatoshi Itoh, Mitsuru Kibayashi, Shunpei Morinobu, Keiichi Nagayama, Shiro Ninomiya, Takane Saito, Yasuhiro Sakemi, Kenji Sato, Atsushi Tamii, Hitoshi Tamura, and Michio Uraki

Research Center for Nuclear Physics, Osaka University
10-1 Mihogaoka, Ibaraki, Osaka 567-0047, JAPAN

Abstract

The RCNP cyclotron cascade system has been operated to serve high quality beams for various experiments. In order to increase physics opportunities, the AVF cyclotron facility is upgraded as one year project in 2004. A flat-topping system and a 18 GHz Superconducting ECR ion source are introduced to improve the beam quality and intensity. A polarized Li^{3+} ion source is designed. Control system and some power supplies are replaced.

INTRODUCTION

The Research Center for Nuclear Physics(RCNP), Osaka University, is a laboratory complex. The main facility is the cyclotron laboratory[1] which consists of K140 AVF and K400 Ring cyclotrons, and unique experimental apparatuses including dual magnetic spectrometers, a neutron detector and polarimeter, a secondary beam line etc. Other laboratories are Laser Electron Photon Laboratory at the SPring-8 site[2] and the underground laboratory at Oto Cosmo Observatory.

The AVF cyclotron was constructed in 1973 and many experimental studies were performed in nuclear physics, atomic physics and interdisciplinary fields. Since the completion of the Ring cyclotron in 1991, it has been mainly used as an injector. The upgrade project of the AVF cyclotron facility has been recently approved to improve the performance as well as to replace old components which are difficult to be maintained today.

In this paper, we will introduce the upgrade programs and perspectives.

OVERVIEW OF THE FACILITY

The schematic layout of the RCNP cyclotron cascade system is shown in Fig. 1. Beams from the AVF cyclotron are transported through the transfer line and injected into the Ring cyclotron. Extracted beams from the Ring cyclotron are distributed to three experimental halls. In the West Hall, two magnetic spectrometers are installed[3]. A spallation neutron source has been constructed to study radiation effects on integrated circuits. In the North Hall, there is a neutron time-of-flight system with 100 m tunnel[4]. The East Hall is equipped with a projectile fragment separator[5], a general purpose scattering chamber and an irradiation system for the biological science. We have recently constructed a superthermal ultracold neutron source there and have succeeded to cool spallation neutrons to ultracold neutrons with a superfluid helium[6].

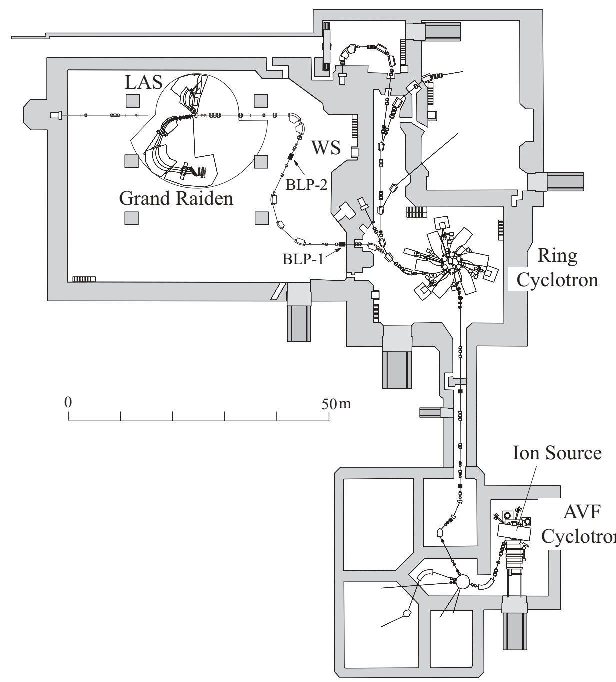

Figure 1: Layout of the RCNP cyclotron facility.

Characteristics of two cyclotrons are summarized in Table 1. Two kinds of external ion sources, atomic beam type polarized ion source[7] and 10 GHz ECR ion source NEOMAFIOS, are installed and ions are vertically injected into the AVF cyclotron through the axial injection line. Experiments have been performed with polarized protons/deuterons and light ions up to ^{18}O. One of the unique points of the RCNP Ring cyclotron is the flat-topping cavity[8] which is successfully operated at the energy variable cyclotron for the first time in the world. With this cavity, it is possible to extract halo-free beams in the single turn extraction mode. Magnetic fields of the sector magnets are well stabilized by the fine control of the cooling water temperature and are kept constant within a relative deviation of a few times 10^{-6} for several days without any current feedbacks. In cooperation with the high intensity polarized ion source, 1 μA polarized protons are available on targets at 400 MeV.

Table 1. Characteristics of the RCNP AVF and Ring cyclotrons.

AVF cyclotron			
Magnet		Acceleration system	
Pole face diameter	2.3 m	Dee	Single 180 degree type
Pole gap	20.6-34.7 cm	Resonator	Moving short
Maximum average field	1.6 T	Frequency	6-18 MHz
Trim coils	16 sets	Accelerating voltage	60 kV
Valley coils	5 sets	Injection system	Spiral inflector
Weight	400 tons	Extraction system	Electrostatic deflector
Ring cyclotron			
Magnet		Acceleration system	
Sector magnets	6 sets	Single gap type	3 sets
Pole gap	6 cm	Frequency	30-52 MHz
Maximum sector field	1.75 T	Accelerating voltage	500 kV
Trim coils	36 sets	RF power	250 kW/cavity
Injection radius	2 m	Flat-topping system	
Extraction radius	4 m	Single gap type	1 set
Weight	2300 tons	Frequency	90-156 MHz

UPGRADE PROGRAM

In order to improve the beam quality for high resolution studies and increase the intensity of heavy ions, following items are being discussed to upgrade the AVF cyclotron.

1. The peak dee voltage is increased to 100 kV from 60 kV which is nominal value in the present operation.
2. A flat-topping voltage is put on the dee electrode. We use 5th to 9th higher harmonics[9].
3. An 18 GHz SuperConducting Electron Cyclotron Resonance Ion Source (SCECRIS) is introduced to produce highly charged heavy ions.
4. A beam line is installed to transport beams from AVF to experimental halls of the Ring cyclotron where such sophisticated apparatuses are available as magnetic spectrometers, the neutron TOF facility, the secondary beam separator, etc.
5. A polarized Li^{3+} ion source is developed by ionizing optically pumped atoms by a surface ionizer and ECR plasma.
6. The accelerator control system is replaced to a system consisting of PC's connected by a local area network system.
7. Some power supplies for trim coils and beam line magnets are replaced, since it is difficult to find electric components today to repair them.

We have performed intensive studies on beam dynamics in the AVF cyclotron since last fall. By optimizing trim coil currents based on the numerical calculations using measured magnetic field distributions, a new set of currents are obtained to produce isochronous fields. They are used as initial values of trim coil currents, and small adjustments are enough to get the isochronous fields monitored by the phase excursion of accelerated beams. With this procedure and reducing the phase of the injected beam at the central region of the AVF cyclotron, we can obtain good turn separations at almost whole radius and extract a single turn even for 65 MeV protons. This had never been realized before last summer. After the acceleration by the Ring cyclotron and utilizing the dispersion matching technique[10], we can routinely obtain spectra with a good energy resolution of 20-30 keV for 300-400 MeV protons and 420 MeV ^{3}He particles. Figure 2 shows a spectrum of $^{54}Fe(^{3}He,t)^{54}Co$ reaction measured at 420 MeV and 0 degree. Higher dee voltages will increase the separation between adjacent turns. The flat topping system will reduce the beam width in each turn although the phase acceptance becomes larger. These two improvements are expected to realize the single turn extraction without large reduction of beam intensity using phase slits. Improved beam quality from the injector can reduce the beam loss at the Ring cyclotron and enable to use high intensity protons to produce spallation neutrons.

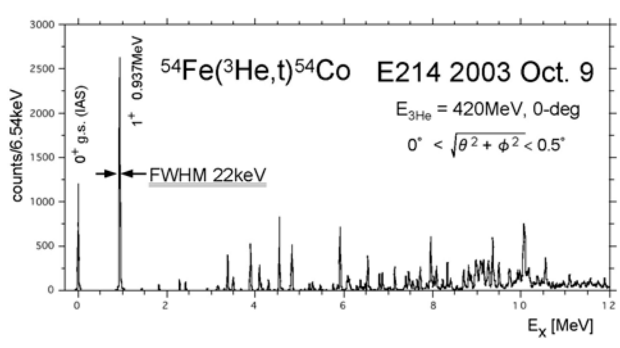

Figure 2: Excitation energy pectrum of $^{54}Fe(^{3}He,t)^{54}Co$ reaction measured at 420 MeV and 0 degree.

The design of the high frequency SCECRIS is similar to that of RAMSES at RIKEN[11]. They report the beam intensities of 20 and 5 eμA for $Kr^{25+, 27+}$, respectively. The resonance conditions for accelerations of various ions are show in Fig. 3. Higher charged Kr ions than 20+ can be accelerated in the fundamental mode and lower charged ions are accelerated in the third harmonic mode. The Ring cyclotron amplifies the beam energy by a factor four. The RCNP cyclotron facility will be able to supply 2-100 MeV/nucleon heavy ions with reasonable intensities.

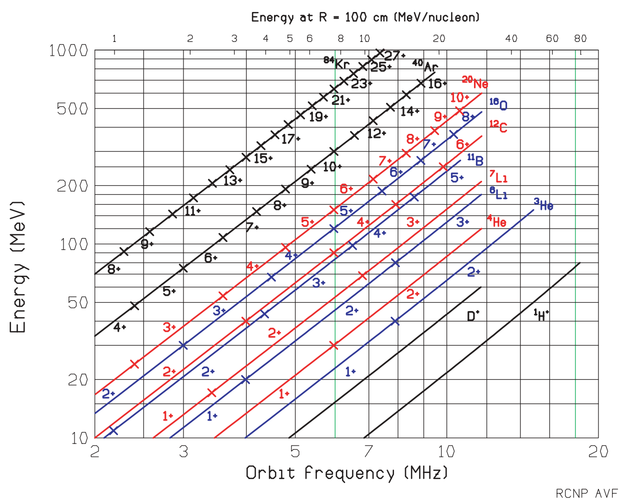

Figure:3: Resonance conditions for ion acceleration

A beam line to deliver the AVF beam to the Ring experimental halls is being designed to diagnose and optimize the quality of the beam which is injected into the Ring cyclotron. From our operational experiences, the final beam quality on targets is usually determined by the quality of the injected beam. However, there have been no available diagnostic devices to precisely measure its emittance and energy spread before injection. The dispersion of the analyzing section is designed to be larger than 10 m.

SUMMARY

The RCNP cyclotron facility is upgraded in 2004. High quality and high intensity beams become available for studies on nuclear physics, fundamental physics and applications.

REFE RENCES

[1] I. Miura *et al.* Proc. of the 13th Int. Conf. on Cyclotrons and their Applications, Vancouver, 1992, p.3.
[2] T. Nakano *et al.*, Phys. Rev. Lett. **91**, 012002 (2003)
[3] M. Fujiwara *et al.*, Nucl. Instrum. and Methods A **422**, 484 (1999).
[4] T. Wakasa *et al.*, Nucl. Instrum. and Methods A **404**, 355 (1998).
[5] S. Mitsuoka *et al.*, Nucl. Instrum. and Methods A **372**, 489 (1996)
[6] Y. Masuda *et al.*, Phys. Rev. Lett. **89**, 284801 (2002).
[7] K. Hatanaka *et al.*, Nucl. Instrum. and Methods A **384**, 575 (1997).
[8] T. Saito *et al.* Proc. of the 14th Int. Conf. on Cyclotrons and their Applications, Cape Town, 1995, p. 169.
[9] T. Saito *et al.*, Contribution to this Conference.
[10] T. Wakasa *et al.*, Nucl. Instrum. and Methods A **482** , 79-93 (2002).
[11] T. Nakagawa *et al.*, Rev. Sci. Instrments **73**, 513 (2002).