PRESENT STATUS OF THE RCNP CYCLOTRON FACILITY

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Abstract

The Research Center for Nuclear Physics (RCNP) cyclotron cascade system has been operated to provide high quality beams for various experiments in nuclear and fundamental physics and applications. In order to increase the research opportunities, the Azimuthally Varying Field (AVF) cyclotron facility was upgraded recently. Developments on the flat-topping system and the 18-GHz superconducting Electron Cyclotron Resonance (ECR) ion source have been continued to improve the beam's quality and intensity. A muon capture beam line (MUSIC) was constructed in this spring. Developments have been going on to increase secondary beams like white neutrons, ultra cold neutrons, muons and unstable nuclei. A separator is equipped to provide RI beams produced by fusion reactions at low energy and by projectile fragmentations at intermediate energy. Developments of magnets using high temperature superconducting (HTS) wires have been performed for future applications to accelerators.

INTRODUCTION

A schematic layout of the RCNP cyclotron facility is shown in Fig. 1. The accelerator cascade consists of an injector Azimuthally Varying Field (AVF) cyclotron (K=140) and a ring cyclotron (K=400). It provides ultra-high-quality beams and moderately high-intensity beams for a wide range of researches in nuclear physics, fundamental physics, applications, and interdisciplinary fields. The maximum energy of protons and heavy ions are 400 and 100 MeV/u, respectively. Sophisticated experimental apparatuses are equipped like a pair spectrometer, a neutron time-of-flight facility with a 100-m-long tunnel, a radioactive nuclei separator, a super-thermal ultra cold neutron (UCN) source, a white neutron source, and a RI production system for nuclear chemistry. A pion capture beam line was installed to provide DC muons. Such ultra-high-resolution measurements as $\Delta E/E=5\text{x}10^{-5}$ are routinely performed with the Grand-Raiden spectrometer by utilizing the dispersion matching technique. The UCN density was observed to be 19 UCN/cm^3 at the experimental port with a beam power of 400 W. The white neutron spectrum was calibrated and the flux was estimated to be 70 % of that obtained at Los Alamos Neutron Science Center (LANSCE) in the USA. Neutrons are used for the radiation effect studies on integrated circuits and so on. Developments of magnets using high temperature superconducting wires have been going on for future applications to accelerators. A 3T dipole magnets is under fabrication.

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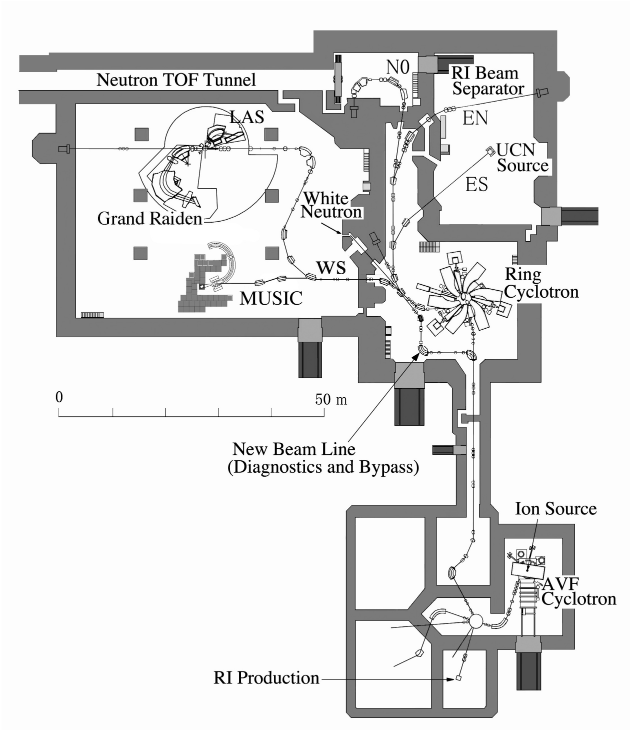

Figure 1: Layout of the RCNP cyclotron facility.

ACCELERATOR DEVEPOLMENTS

User's demands on the high beam quality are expanding rapidly: ultra-high resolution, high intensity, a variety of heavy ions. Since there are no slits or collimators in the beam lines downstream of the ring cyclotron, the beam quality on targets is determined by the characteristics of the injected beam. The AVF upgrade program for these items is in progress [1-3]. Some of them are presented in these proceedings [4,5].

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 production development of several ion beams and their acceleration by the AVF cyclotron has been performed since 2006.

In order to improve the performances of the source, a liner was inserted in the plasma chamber. A bias probe was 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 center of the chamber.

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 downstream of the extraction electrodes.

The ion beams extracted from the source are analyzed by using a dipole magnet and are measured in a Faraday cup placed at the image focal point of the analyzing system. Detailed performance of the source is presented somewhere in these proceedings [4]. 8.5 MeV/u $^{86}Kr^{23+}$ ions were accelerated by the AVF cyclotron and were delivered to user's experiments. In order to produce metallic boron-ions, a test by using the MIVOC (Metal Ion from VOlatile Compounds) method [6] was performed using o-carborane ($C_2B_{10}H_{12}$). Its vapour pressure was around 1-2 Torr at the room temperature. The o-carborane was put in a glass vessel directly connected to the plasma chamber via a buffer tank. The stable flow of the vapour from the o-carborane powder to the plasma chamber enabled us to produce a fully stripped boron ions. A helium gas was used to generate plasma..

2.45 GHz ECR Proton Source

A proton source is under development to supply high currents with a low emittance. It consists of three ring permanent magnets and no multipole magnets are employed. Performance tests were finished and 0.6 mA protons were extracted at 15 kV and with a relatively low RF power of 200 W. The source has been installed in the injection beam line. On-line tests will be started this fall.

Flat-Topping Acceleration System

A schematic layout of the main and the flat-top resonators of the AVF cyclotron is shown in Fig. 2. An additional flat-top cavity of a coaxial movable-short type is inductively coupled to the main resonator on the opposite side of the main power feeder for fundamental-voltage production. The flat-top cavity has a length of 700 mm and an outer diameter of 170 mm. A full stroke of the shorting plate of the flat-top cavity is 100 mm. The coupler electrode and the inner conductor of the flat-top cavity are shown in Fig. 2. The capacitive coupling between the electrode and the inner tube of the main cavity was changed to the inductive coupling from the capacitive coupling in order to avoid heating problems. Fine adjustment for 50Ω impedance matching is accomplished by using a tuner with a full stroke of 40 mm.

A flat-topped dee voltage waveform can be generated by superimposing a harmonic voltage on the fundamental one [7]. With the present cavity, the impedance matching can be achieved over a wide range of harmonic frequencies from 50 to 80 MHz. Hence, the fifth, seventh, and ninth harmonic modes are available for production of the flat-topped voltage waveform. Such higher order harmonic modes have an advantage of saving power for the harmonic voltage production, because the n-th harmonic voltage required for flat-toped waveform production is $1/n^2$ of the fundamental one [5, 8]. For the present structure of the Dee electrode, a parasitic resonance mode is known to exist around 76 MHz. This resonance is generated in the transversal direction of the dee electrode axis. Beam developments are on-going with the FT system [5].

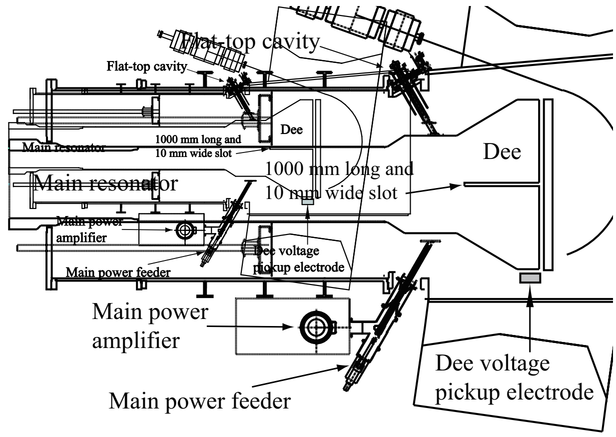

Figure 2: Cross-sectional view of the accelerating system of the RCNP AVF cyclotron.

DEVELOPMENTS OF HTS MAGNETS

More than two decades have passed since the discovery of high-temperature superconductor (HTS) materials in 1986 [9]. Significant efforts went into the developments of new and improved conductor materials [10] and it became possible to manufacture relatively long HTS wires of the first generation [11]. Although many prototype devices using HTS wires have been developed, these applications are presently rather limited in accelerator and beam line facilities [12].

Our previous study demonstrated a possibility to excite HTS magnets with alternating currents (AC) [13,14]. Since HTS systems have higher operating temperatures than low-temperature superconductor (LTS) systems, the cryogenic components for cooling are simpler and the cooling power of refrigerators is much larger than at 4K. Because the temperature range for superconductivity is wider than for LTS materials, a larger range of operating temperatures is available. A high-frequency AC mode operation should be possible in spite of heating loads due to AC losses in the coils.

In order to investigate feasibilities of synchrotron magnets using HTS wire, we are fabricating a super-ferric dipole magnet to be operated by lumping currents. The specifications are summarized in Table 1. Upper and lower coils were already fabricated. Each consists of 3 double pancakes of 200 turns. Figure 3 shows double pancakes for the upper coil. Critical currents of wire were measured in full length at 77K. Self-field Ic of wire was higher than 160A. Ic values of double pancakes were 60-70A. After stacking, they were 47A and 51A for the upper and lower coil, respectively. There were no damages in wire during winding process.

Table 1: Design parameters of the 3T HTS dipole magnet.

Magnet	Bending radius	400mm
	Bending angle	60deg.
	Pole gap	30mm
Coils	# of tturns	600 x 2
	Winding	3 Double pancakes/coil
	Temperature	20K
	Rated current	300A

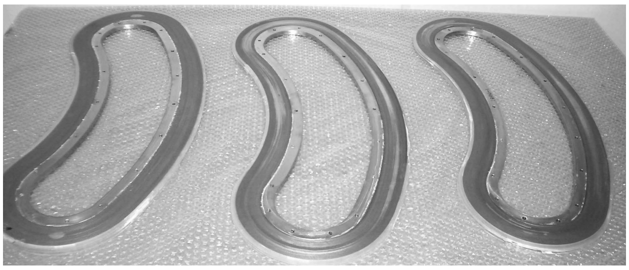

Figure 3: Photograph of double pancakes.

RESEARCH PROGRAMS

Beams are available on targets for 5000-6000 hours in a year. A wide range of research programs are performed at the RCNP cyclotron facility as listed below.

- Few-body problem
- Nucleon and nuclear interactions in nuclear medium
- Proton/deuteron elastic & inelastic scattering
- (p,2p), (p,n), (p,t) reactions
- Charge exchange reactions relevant to the astronuclear physics: (^{4}He,^{6}He), (^{4}He,^{8}He)
- Giant resonance excited by（p,p’）, (^{3}He,t), (α,α’), (^{7}Li,^{7}Be γ) reactions
- Fragmentation of deep hole states in light nuclei
- Proton-proton Bremsstrahlung (p,p’γ) reaction
- Weak hyperon nucleon interaction by the pn → pΛ reaction
- Heavy ion physics with rare isotopes
- Fundamental physics with ultracold neutrons
- Applications (neutrons)
  Material science
  Biological science
- Nuclear chemistry

Intensive studies have been performed on the spin and isospin excitation by charge exchange (p,n) and (n,p) reactions around 300 MeV. The $\sigma\tau$ nucleon-nucleon interaction has the maximum strength at this energy region. The mechanism of these reactions is simple, as well. We can extract the spin and isospin excitation strength with least ambiguities. Recent result showed the strength distribution in the nuclei relevant to 2ν double β decays [15] of ^{48}Ca.

A beam line was installed to bypass the ring cyclotron and to directly deliver low-energy, high intensity beams from the AVF cyclotron to experimental halls. With this line, low energy heavy ions are delivered to the rare isotope separator and are used to study high spin isomeric states in nuclei.

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