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PRESENT STATUS OF THE RCNP RING CYCLOTRON

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Abstract

The RCNP ring cyclotron is in operation for nuclear physics experiments. The beam extracted from the K=140 AVF cyclotron is injected into the ring cyclotron. This accelerator system can accelerate p, d, ^{3}He, alpha and light heavy ions up to 400, 200, 510, 400 Q^2/A MeV, respectively. This paper gives a brief summary of the ring cyclotron and the status of the operation is described.

Injector (AVF Cyclotron)

The K=140 AVF cyclotron[1] is used as an injector of the ring cyclotron. The AVF cyclotron is a three sector, single dee, variable energy machine which can accelerate p, d, ^{3}He, alpha and various light heavy ions up to 80 MeV, 70 MeV, 175 MeV, 140 MeV and 140 Q^2/A, respectively. The specification is listed in Table 1.

Ring Cyclotron

The first beam of 300 MeV protons was successfully extracted from the ring cyclotron[2] in the autumn of 1991. Up to the present since the first extraction, the ring cyclotron has accelerated some kind of ions. High quality beam with energy spread of less that 0.05% and a pulse width shorter than 500psec has been extracted. More improvement of beam quality, stability and beam intensity is being continued. Table 1 shows the specification of the ring cyclotron and fig. 1 shows a photograph and a schematic plane view of the ring cyclotron.

Magnet System: The main magnet system[3] consists of six spiral separated sector magnets. The maximum magneto-force is about 1.4×10^{-5} ampere-turns to obtain the maximum field strength of 17.5 kG. Isochronous fields are created by a main coil and 36 pairs of trim coils mounted on the pole faces. High current stability is required for the power supplies of main, auxiliary and trim coils to obtain a high quality beam. In order to achieve high stability, a precision shunt resistance made of germanium-manganese-copper alloy (ZERAMIN) is used as a current sense. The temperature coefficient of the shunt resistance is less than 3 ppm/°C between 15°C and 40°C. The shunt resistances are cooled by temperature controlled water. The current stability of $\pm 2 \times 10^{-6}$ is obtained for main coil currents.

Injection and Extraction System: The extracted beam from the AVF cyclotron is well shaped and momentum-selected and the double achromatic beam is formed at the transport line. The injection line[4] operates as a matching section to the ring cyclotron. The elements are four bending magnets, several quadrupole magnets, steering magnets, two magnetic channels and two electrostatic channels as shown in Fig. 1. The extraction system[4] consists of two electrostatic channels, two magnetic channels, two bending magnets and several quadrupole magnets. This extraction line operates as a matching section to the beam transport system. At the matching point, the double focusing and the double achromatic beam is formed with the extraction elements.

RF System: The RF system[5] consists of three single gap acceleration cavities and a single gap flat-topping cavity to get high quality beam. The frequency range of the acceleration system is 30-52 MHz and the harmonic numbers of the acceleration are 6, 10, 12 and 18. The frequency range of the flat-topping cavity is 90-156 MHz, which corresponds to the third harmonic of the acceleration frequency. A schematic drawing of the acceleration cavity is shown in Fig. 2. The resonance frequency is changed by rotating a pair of capacitive plates. The 250 kW power amplifiers are used for the acceleration. A schematic drawing of the flat-topping cavity is also shown in Fig. 2. The resonance frequency is changed by a pair of sliding tuning panels.

Table 1
Specification of the RCNP AVF cyclotron and the Ring cyclotron

	AVF Cyclotron	
Maximum energy	p	85 MeV
	d	70 MeV
	^{3}He	175 MeV
	alpha	140 MeV
	light heavy ions	$140 \cdot Q^2/A$
Magnet	Pole face diameter	230 cm
	Maximum average field	16 kG
	Extraction radius	100 cm
	Weight	400 tons
Acceleration system	Frequency	5.5-19 MHz
	single dee peak power	200 kW
	Ring Cyclotron	
Maximum energy	p	400 MeV
	d	200 MeV
	^{3}He	510 MeV
	alpha	400 MeV
	light heavy ions	$400 \cdot Q^2/A$
Magnet	Sector magnet	6 sets
	Pole gap	6 cm
	Maximum magnetic field	17.5 kG
	Injection radius	2 m
	Extraction radius	4 m
	Total weight	2200 tons
Acceleration system	Acceleration cavity (single gap type)	3 sets
	Frequency	30-52 MHz
	Maximum voltage	50 kW
	RF power	250 kW/cavity
	Flat-top cavity	1 set
	Frequency	90-156 MHz

Vacuum System: The vacuum chamber[6] of the ring cyclotron consist of twelve separated chambers, which are six magnet-chambers, three RF cavity chambers, one flat-topping chamber and two valley chambers. These chambers are connected with pneumatic expansion seals. The roughing pumping system is composed of rotary pumps, a mechanical booster and turbo-molecular pumps. We can pump down the vacuum chamber of the ring cyclotron to 10^{-7} Torr using the diffusion pumps with freon cooled chevron baffles and cryopumps.

Beam Diagnostic System: In order to optimize the operation of the ring cyclotron, the beam diagnostic system[7] which consists of various types of the diagnostic devices has been designed. The system consists of multi-finger main probe, wire profile monitors, phase probes of capacitive pickups, emittance monitors, TV profile monitors, beam stoppers and various types of slits. The devices are distributed at the injection and the extraction beam lines and inside the cyclotron.

Control System: The computer control system^8 consists of a central computer (system controller), sub-computers (group controller) and universal intelligent device controllers. Each group controller is connected to the system controller through Ethenet. A controlled device has an universal device controller. Each device controller is connected to a group controller through optical fiber serial line. Each device controller has a microcomputer chip and excutes several tasks such as device controls, communications etc.

Status of Acceleration

The kind of ions and the energies are listed in Table 2.

Transport and Injection to the ring cyclotron: The pulse width of the beam extracted from the injector is limited to about 1 nsec using a phase slit in the injector. The dispersion of the extracted beam is determined by adjusting the strengths of quadrupole magnets in the transport line. The momentum width and the emittance of the beam are defined by slit width. The beam is injected through valley vacuum chamber into the central region of the ring cyclotron as shown in Fig. 1. The beam is guided onto the desired orbit for acceleration with the injection components. With optimization of the injection system. about 100% beam transmission through the injection system is achieved regularly. Figure 3 shows an example of the beam profile measured by a three wire profile monitor in the injection line. Figure 4 shows the injection orbit and the first turn orbit.

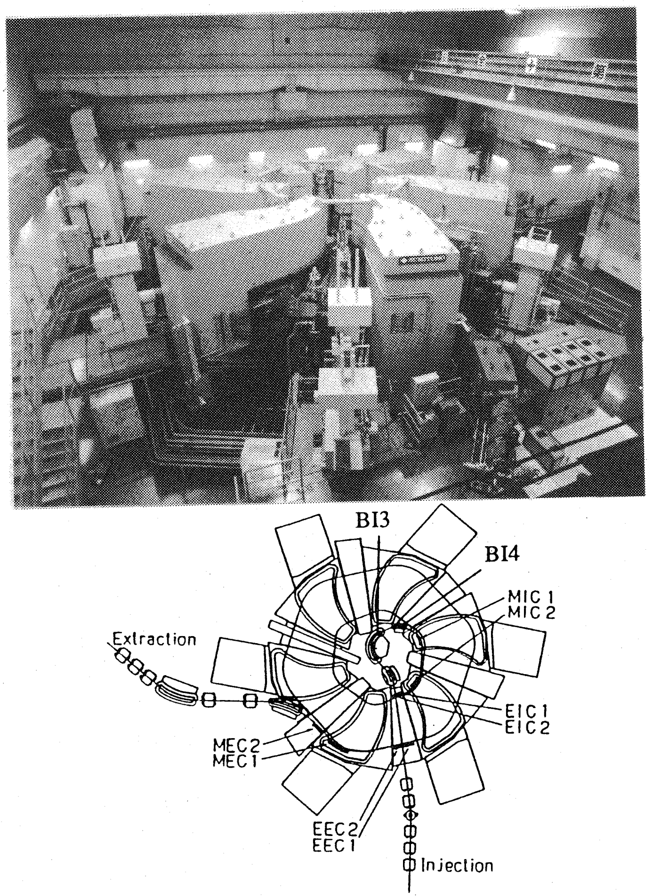

Fig. 1. Photograph and the schematic plane view of the ring cyclotron.

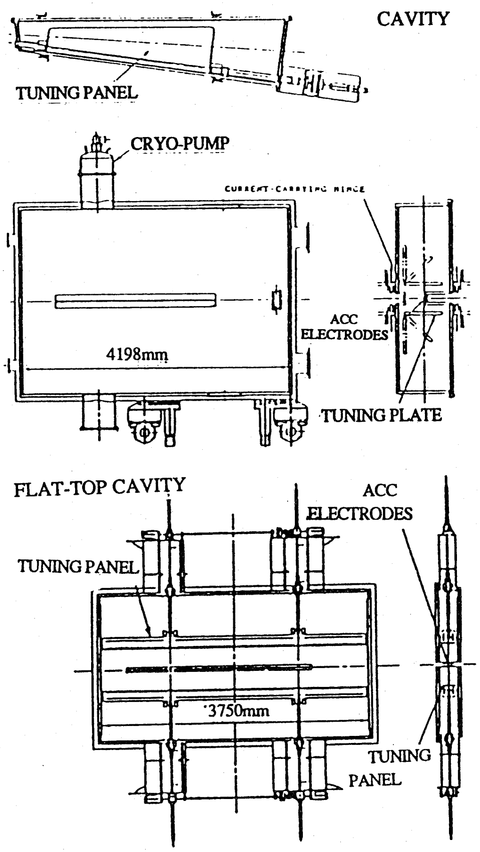

Fig. 2. Schematic view of the acceleration and flat-topping cavities.

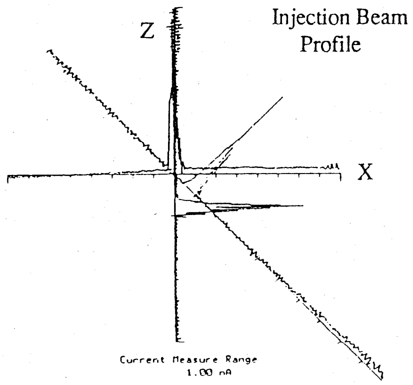

Fig. 3. Beam profile measured by a three wire profile monitor in the injection line.

Table 2

Accelerated ions by the ring cyclotron up to the present

Proton	200,	300,	350,	380
	390,	400	MeV	
Deuteron	150,	170,	200	MeV
			(Alpha 400 MeV)	
^{3}He	450	MeV		
Alpha	300	MeV		

Acceleration: For all beams, it is possible to accelerate the particles to full radius with pre-calculated setting of the trim coils and the harmonic coils by only adjusting the main field. The necessary change of the main magnet current to achieve this was always less than 0.4%. The phase history of the beam can be measured with a phase measuring system. The field is isochronized by a slight adjustment of the trim coil currents. Figure 5 shows the initial phase history and the optimum phase history predicted for 400 MeV proton acceleration. Figure 6 shows an example of the beam current and the turn pattern from the injection region to the extraction radius measured a integral probe and a wire probe.

Extraction: Special attention is paid to obtain fairly well centered orbit with clear turn separation at the extraction radius. Figure 7 shows the turn pattern in the extraction taken with a wire probe. The high extraction efficiency of more than 90% can be obtained as shown in Fig. 7. We can obtain the beam energy resolution of about 3×10^{-4} when energy selection is made in the injection transport line. In the case without energy selection in the injection line, the beam energy resolution is about 0.1%. The pulse time width of the extracted beam is always about 0.5 nsec.

We have accelerated ions listed in Table 2 during this one and half year. The stability of the extracted beam from the ring cyclotron go bad sometimes because the phase of the beam from the injector is not so much stable. The 400 MeV proton beam seems to have a large vertical oscillation amplitude at about 3.7m. This results in significant beam loss. The beam loss at the extraction where ν_z is near one, is 30-50%. These problems are in improvement.

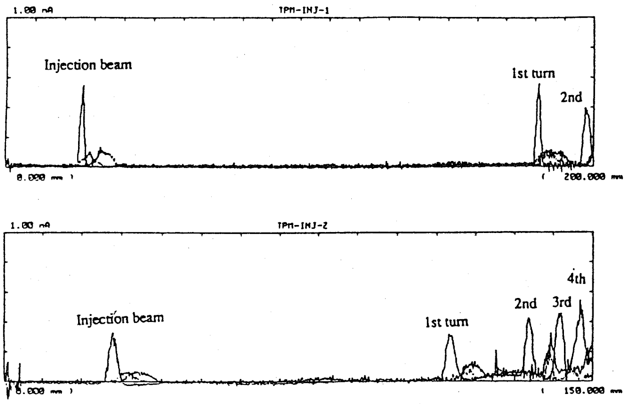

Fig. 4. Injection beam and acceleration beam measured by a wire probe in the ring cyclotron.

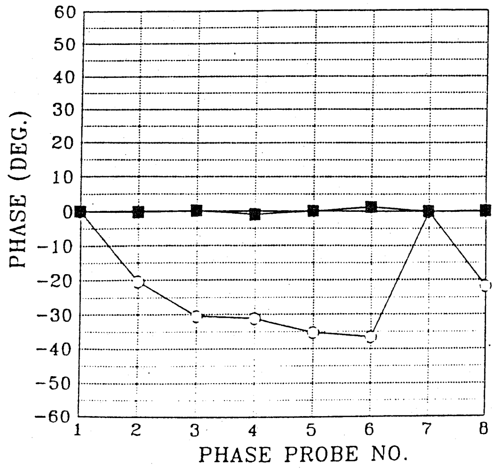

Fig. 5. Example of initial phase history and the optimum phase history for 400 MeV proton acceleration.

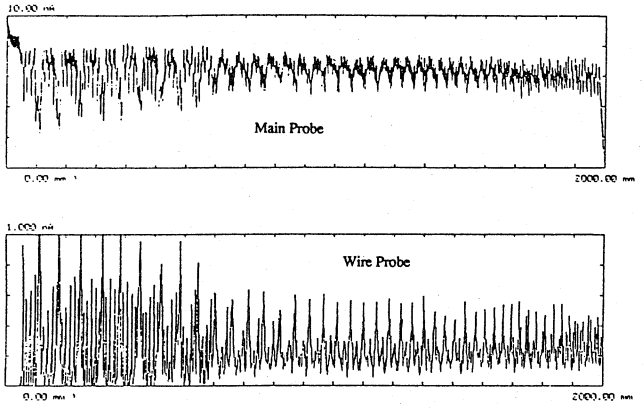

Fig. 6. Beam current and turn pattern from the injection region to the extraction radius.

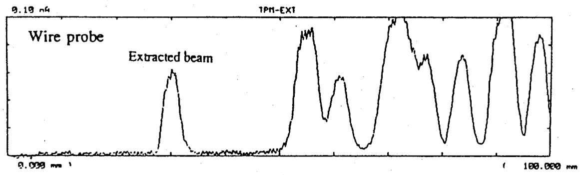

Fig. 7. Turn pattern at the extraction taken with a wire probe.

References

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