OPERATING STATUS OF THE RCNP SEPARATED SECTOR CYCLOTRON

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The RCNP six spiral separated sector cyclotron is in operation for intermediate energy nuclear physics experiments. The beam extracted from the AVF cyclotron is injected into the ring cyclotron. This accelerator system can accelerate protons, deuterons, ^{3}He, alpha-particles and light heavy ions up to 400, 200, 510, 400 and 400Q^2/A MeV, respectively. An emphasis is placed on the production of high quality beam to enable precise experiments. In order to get more high quality and more high intensity beam, the RCNP cyclotron system has been upgraded according to the improvement programs. This paper presents the status of the operation and the practical beam quality obtained during acceleration, and the results of the improvements and developments.

1 Introduction

Up to the present since the first extraction, the accelerator complex of RCNP has accelerated various kinds of ions and high quality beam with the high resolution of energy and the good time resolution. The beam extracted from the AVF cyclotron is transported through one of the beam line of the low energy nuclear physics facility and is injected into the ring cyclotron. The beam extracted from the ring cyclotron is delivered to three experimental halls for intermediate energy nuclear physics.

2 AVF Cyclotron(Injector)

The K=140 AVF cyclotron is used as an injector of the ring cyclotron. The AVF cyclotron is a three-sector, 180°-single dee variable energy machine which can accelerate protons, deuterons, ^{3}He, alpha-particles and various light-heavy ions up to 80, 70, 175, 140 and 140Q^2/A, respectively. By 16-trim coils, any isochronous field can be produced. The wide RF frequency range from 5.5MHz to 19MHz permits acceleration of ions in very wide energy region by using fundamental and third harmonic modes without energy gap. The specifications are listed in Table 1.

3 Ring Cyclotron

The extracted beams from the AVF cyclotron are well shaped and momentum selected by various slits, and the double achromatic beams are formed at the transport line. In order to inject various quality beams to the ring cyclotron, some apparatus for the detailed treatments of the beam such as various slits, a beam pulsing device, spin-rotator, a charge stripper, a buncher and diagnostic elements are placed in the injection line. The accelerator system can accelerate protons, deuterons, ^{3}He, alpha-particles and heavy ions up to 400, 200,510, 400 and 400Q^2/A MeV, respectively. The specifications are listed in Table 1. Detailed specifications of the various parts are described elsewhere[1].

Table 1: Specifications of cyclotrons.

	Injector	Ring cyclotron
No. of sector magnets	3	6
Injection radius(cm)		200
Extraction radius(cm)	100	400
Magnet gap(cm)	20.7(min)	6.0
Max. field(kG)	19.5	17.5
No. of trim coils	16	36
No. of acceleration cavity	1	3
Frequency(MHz)	5.5 - 19	30 - 52
Max. voltage(kV)	70	550
No. of flat-topping cavity		1
FT frequency(MHz)		90 - 156
FT Max. voltage(kV)		170
Ion sources(external)	HIPIS ECR	

4 Improvements

The accelerator complex can accelerate various ions from low energy to intermediate energy region. In addition to this ability, the system can accelerate high quality beams with the high resolution of energy and the short time width. In order to get more high intensity, more stable and more high quality beams, improvements and developments have been carried out.

4.1 New External Ion Sources

In order to increase beam intensity, new ion sources which are a high intensity polarized ion source(HIPIS) and a NEOMAFIOS ECR ion source, and a new vertical injection system were installed in 1994. The new polarized ion source[2] is a 40°K-cold atomic beam type and

Table 2: Examples of the beam intensities from the external ion sources (eμA).

ions	p	^{4}He	^{6}Li	^{14}N	^{16}O	^{20}Ne	^{40}Ar
polp,d	500						
1^+	500	1100	10			29	
2^+		580	16			100	34
3^+			2			145	50
4^+				110	180	96	51
5^+				65	85		
6^+				6	35	16	47
7^+					2	4	35
8^+							35
9^+							9

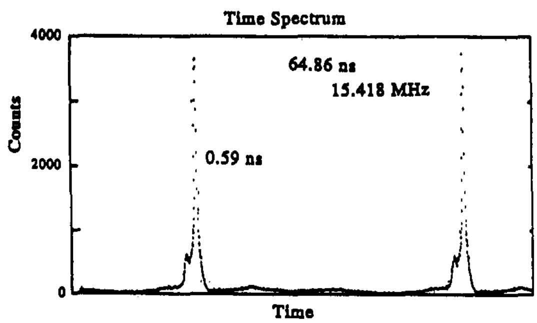


Figure 1: Time width of the extracted beam from the injector

consists of an ECR ionizer. The beam intensity from the source is about 500μA and the polarization is about 75 %.

The NEOMAFIOS ECR ion source[3] of 10 GHz RF frequency developed at CEA in Grenoble was also installed near the polarized ion source. This source is used for light and light-heavy ion acceleration. The beam intensities of various ions from these ion sources are listed in Table 2.

4.2 New Vertical Injection Line to the Injector

A new vertical injection system[2] to the injector was also installed. In the injection system, electromagnetic lenses are used instead of the electrostatic ones used in the old system.

The beams from the ion sources are axially injected into the center of the injector cyclotron by a spiral inflector instead of the electric mirror system used over a long period of time. The injection energy is 15keV for 65 MeV protons. A buncher which is excited by RF voltage with a sawtooth-like wave generated by combining a sine wave with the first three harmonics, is installed in the injection line. The beam intensities extracted from the cyclotron increase by a factor of 3-6 by using the buncher. Due to the increase of the beam intensities, good energy resolution and good time resolution can be obtained finely and easily, because the six dimensional phase space volume

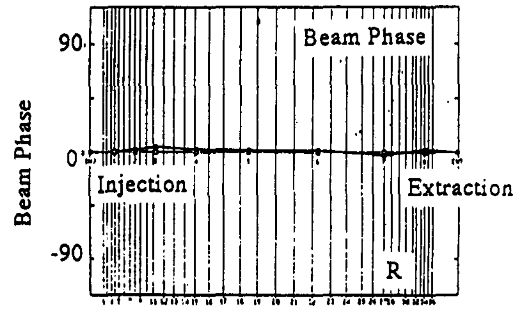


Figure 2: Phase history of 300MeV proton acceleration

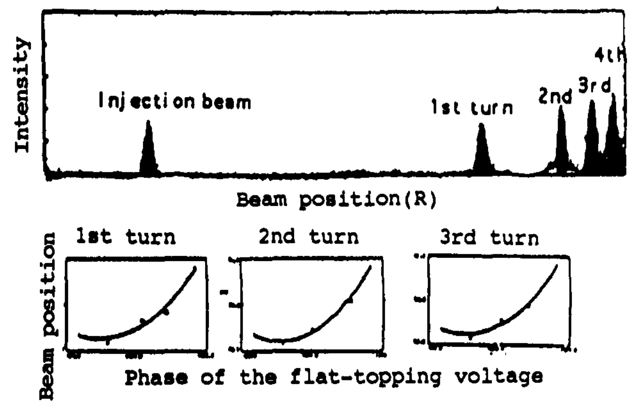


Figure 3: Automatic search of the optimum phase of the FT voltage.

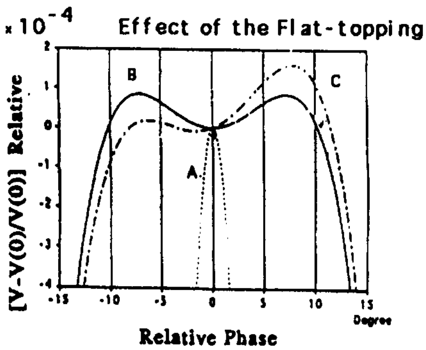
of the beam can be limited precisely by the various slits on the injection line to the ring cyclotron. Normally, we can obtain the polarized proton beam intensity of about 500nA with 0.1% of the energy resolution on a target.

4.3 Power Supplies of the Injector

Improvements of power supplies of the injector and the beam transport line were done to get more high stable beams. The power supply of the main coil of the injector was exchanged to new one to get more stability, because the old power supply was used for more than 20 years. The stability was made better from 5x10^{-5} to 4x10^{-6} as similar as the power supply of the main coil of the ring cyclotron. The old DCCTs used for the trim coil power supplies of the injector were exchanged to new ones to get more stability. The stabilities were improved from 1x10^{-4} to less than 1x10^{-5}. The potentiometers used for the reference voltages in the all power supplies of the injector were changed to the temperature controlled DAC method for numerical-value settings.

4.4 Cooling System of the Injector

An improvement was made to the cooling system of the injector to ensure better beam stability. The temperature control devices of the cooling water were added to the system. The beam stability for a long time has become



A: Acceleration voltage.
B: With FT of the optimized voltage and phase.
C: With FT of the phase deviation of 0.1 deg. from the optimum.

Figure 4: Effect of the flat-topping system.

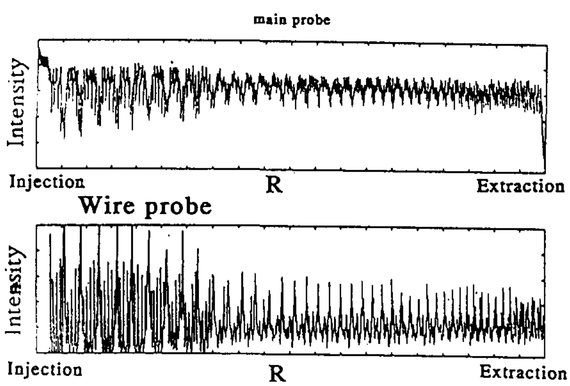


Figure 5: Acceleration beam current and turn pattern measured by an integral and a wire probe.

better due to the improvements of the power supplies and the temperature controlled cooling system.

4.5 Control System of the Injector

The old control system of the injector and the beam transport system to the ring cyclotron was replaced to the computer control system and the control system was included in the control system of the ring cyclotron. So we can control two cyclotrons and the transport system through same touch panels on the control console. This system includes the accelerator operation, optimization of the operation parameters and measurements of the beam characteristics. The various software are being made for the beam stabilization.

5 Acceleration

5.1 Injection to the Ring Cyclotron

The time width of the beam extracted from the injector is limited to about 1ns using a phase slit in the injector. Figure 1 shows an example of the time width of the extracted beam from the injector. The dispersion of the

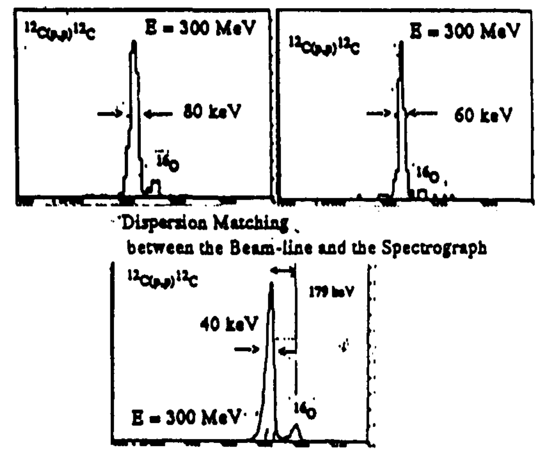


Figure 6: Momentum spectra of $^{12}C(p,p)$ elastic scattering at 300 MeV.

extracted beam is determined by adjusting the strength of quadrupole magnets in the transport line. The momentum width and the emittance of the beam are defined by a slit width. With optimization of the injection system, about 100% beam transmission to the ring cyclotron through the injection system can be achieved regularly.

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. The field is isochronized by a slight adjustment of the trim coil currents. The phase history of the beam can be measured with a phase measuring system. Figure 2 shows a phase history of the 300 MeV proton acceleration.

The Flat-Topping system is used to accelerate high quality beam and to extract the beam with single turn mode. The optimum deceleration voltage of the FT cavity is 11.37 % of the total acceleration voltage. The phase of the FT voltage is adjusted to minimize the energy gain per one turn by measuring the beam positions of the 1st, 2nd and 3rd turn by a main probe. Figure 3 shows a result of the automatic search of optimum phase of the FT voltage. We can obtain the phase acceptance of about 20° by the optimum phase and voltage of FT. The effect of the flat-topping system is shown in Fig. 4. Figure 5 shows the beam current and turn pattern from the injection to the extraction radius measured by an integral and a wire probe in the optimum condition of the flat-topping system.

5.2 Characteristics of the Beam

The beam is extracted with single turn extraction mode using flat-topping method. The high extraction efficiency of more than 90% can be always obtained. Typically, the extracted beam has an energy spread less than 0.1%, a time spread of 0.3 - 0.5ns and an emittance of about 1πmm-mrad. By transporting the extracted beam from

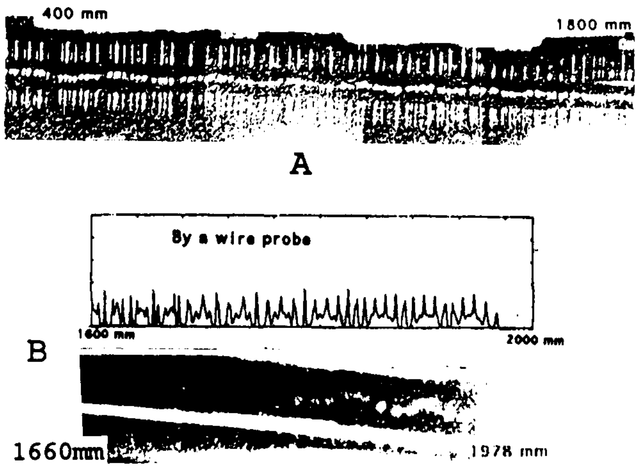


Figure 7: Observed vertical motion of the 400 MeV beam. A:vertical motion of normal acceleration. B:the case when we make the beam oscillate at the injection.

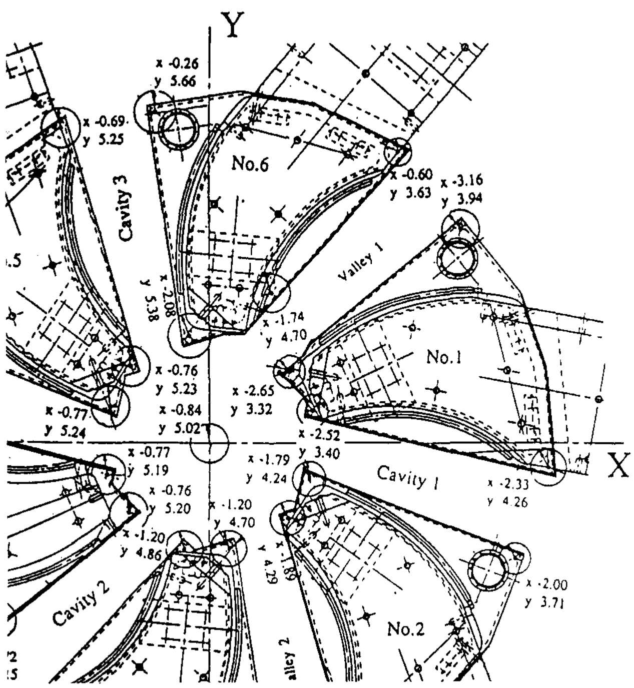


Figure 8: Status of the movement of the ring cyclotron by a earthquake.

Table 3: Beam Quality used in Experiments, Energy in MeV.

Beams	Energy	Energy width	Time width
p	100-400	$\Delta E/E \sim 10^{-3}$	200-500ps
	100-400	$\leq$100keV	150-400ps
d	200	$\leq$200keV	400ps
^{3}He	450	100-400keV	500ps
Alpha	400	$\leq$400keV	500ps
^{14}N	560	500keV	1000ps

the injector with dispersion mode and by defining the beam by the slits, we can obtain a beam energy width of less than 80keV for 300-400MeV protons. An energy width of 25-40keV has been obtained using dispersion matching with a high resolution spectrograph. The beam energy width fluctuates depending on the FT phase variation. A very short time width of 150ps has been achieved by defining the beam by a phase slit. Figure 6 shows the momentum spectra obtained by ^{12}C(p,p) elastic scattering at 300 MeV. In Table 3, the beam quality used for experiments are listed.

5.3 Measurements of the Vertical Motion in Acceleration

We measured the accelerated beam behavior using a beam viewer. The beam viewer of a phosphor plate of ZnS was attached in front of the copper beam stopper of a main probe. The observable radial range at one measurement is about 600mm and we took the pictures with a TV monitor camera outside the vacuum chamber. The observed vertical oscillation of the beam is shown in Fig. 7. In normal acceleration, we could not observe large vertical oscillation. When we made a beam oscillate vertically at the injection, we could see the large vertical motion of the beam as shown in Fig.7.

6 Movement by a Earthquake

A big earthquake ran through our district on 17th of January in 1995. Unfortunately, the ring cyclotron was moved about 5mm by the earthquake. Figure 8 shows the status of the movement of the ring cyclotron. We have already brought the cyclotron back to where it was and started to accelerate various ions and to make the joint-use experiments from the 1st, May in 1995.

7 Summary

The accelerator complex of RCNP can accelerate various kinds of ions in the wide region from low to intermediate energy and also can accelerate high quality beam with the high resolution of energy and time width. The developments have been carried to improvement these characteristics further and we have obtained more stable, more high quality beams and more high intensity beams.

References

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