PRESENT STATUS AND DEVELOPMENTS AT THE OSAKA RCNP CYCLOTRON

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ABSTRACT

The RCNP cyclotron and experimental facilities have been satisfactory operated for many kind of nuclear research experiments. Since Jan. 1977, 17 times research programs, more than 300 experiments, were performed during 8 years. In these times, about 15% of whole machine time were expended for improvement and development of accelerator and experimental facilities.

In this report, operational status of 230cm RCNP cyclotron, some developed points are presented.

BRIEF DESCRIPTION OF THE RCNP CYCLOTRON

The cyclotron is a three-sector, single-dee machine designed for versatility of accelerated ions and energies.[1] The cyclotron K number is 120 and focussing limit is about 85 for protons.

The RF system consists of $1/4\lambda$ mode coaxial resonator with a sliding short and a MOPA system using an RCA 4648 tetrode as a power tube.

The frequency range from 5.5 to 19.6 MHz permits acceleration of particles with very low energies without an energy gap by using the third harmonic acceleration.

Three types of ion sources are employed to accelerate light ions, heavy ions and polarized ions. One is a normal Oak lidge type installed axially in the lower yoke. For heavy ions, cold cathode PIG source is replaced to the normal ion source. The polarized ion source is located on the second floor outside the cyclotron vault. It is the atomic beam type with ANAC ionizer. The beam is axially injected into the cyclotron through several focusing lenzes. The beam is then inflected by 90° at the center of the cyclotron by a electric mirror inflector.

ACCELERATOR PERFORMANCE AND OPERATION

The cyclotron has been generally operated weekly. It starts at 21:00 on Monday and ends at 9:00 on Sunday morning. In these operating hours, sometimes several groups share these times, and sometimes only one group use these times completely depending their experimental schedule and their conditions. Even in one group, their are several choice both in energy and in particles occasionally.

Particles and energies accelerated in recent 5 years are listed in table 1.

The number of change of the accelerated particles, their energies and the beam courses are listed in Table 2.

Table 1

Particles and energies accelerated in recent 5 years

particles	energy (MeV)
p	8, 11, 15, 19, 24, 30, 35, 40, 45, 50, 51, 52, 55, 60, 61, 65, 68, 70, 75, 80, 85
d	50, 54, 56, 57, 60, 70
^{3}He	40, 60, 70, 90, 100, 110, 120, 130, 140, 145, 150, 160, 165, 170
p	25, 35, 40, 45, 50, 53, 55, 60, 61, 65, 70, 75, 80, 85
	30, 40, 47, 50, 60, 65, 70, 80, 85, 90, 100, 109, 110, 120, 130, 140
d	43, 45, 52, 54, 55, 56, 60, 65, 70
$^{6}Li^{2+}$	80
$^{6}Li^{3+}$	125, 150, 170, 180
$^{7}Li^{2+}$	68
$^{7}Li^{3+}$	114, 120, 132, 150, 156
$^{11}B^{3+}$	95, 100
$^{11}B^{4+}$	150
$^{12}C^{4+}$	80, 90, 100, 110, 120, 140, 160
$^{12}C^{5+}$	146, 186, 215
$^{13}C^{3+}$	54, 56, 80, 87
$^{13}C^{4+}$	98, 150, 156
$^{13}C^{5+}$	172

particles	energy (MeV)
$^{14}N^{4+}$	110, 115, 125, 129, 130, 135, 140
$^{14}N^{5+}$	135, 160, 206, 210
$^{15}N^{4+}$	96, 100
$^{16}O^{4+}$	80
$^{16}O^{5+}$	140, 145, 180
$^{18}O^{5+}$	160
$^{20}Ne^{4+}$	22, 28, 85, 88, 90, 95
$^{20}Ne^{5}$	150
$^{20}Ne^{6+}$	217
$^{20}Ne^{7+}$	254
$^{22}Ne^{4+}$	76
$^{22}Ne^{5+}$	118, 144
$^{40}Ar^{4+}$	42
$^{40}Ar^{5+}$	44, 73, 108
$^{40}Ar^{6+}$	48, 108
$^{40}Ar^{7+}$	150
$^{40}Ar^{8+}$	196

Table 2

The number of change of the accelerated particles, their energies and the beam courses during 5 years and the number of change between polarized beam and unpolarized one is also shown.

	particles	energy	beam course	*the change
1979	110	140	88	8
1980	96	116	88	7
1981	103	124	88	7
1982	95	137	87	9
1983	97	136	102	9

* the change between polarized and unpolarized beam

Especially, as shown in Table 2, some electrode in the center region must be changed in order to accelerate a poralized or an unpolarized beam. At that time the cyclotron vacuum chamber must be opened to the air, so, the experimental periods of polarized and unpolarized beam is interchanged about every two months alternately.

In recent years, more than 5000 hrs. beam time have been expended for experiments and running hours of main coil power supply read to 5700 hrs. in 1983.[2] The total account of the operational times during the last 7 years is shown in Fig. 1.

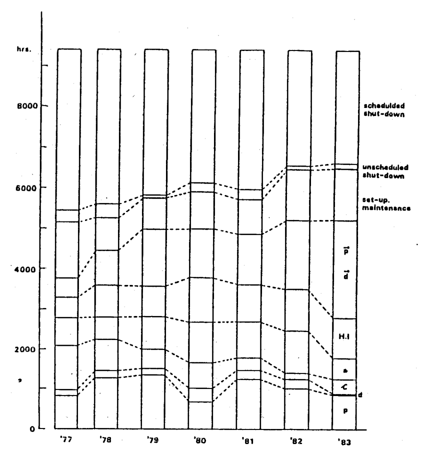

Fig. 1. Operation of the RCNP cyclotron during the last 7 years.

It should be stressed that the beam time for polarized particles exceeded 40% of all beam times. The statistics in 1983 are shown as follows. The account of the operation times and cumulative sums of acceleration periods for different particles are listed in Table 3 and Table 4 respectively. The distinguished point shown statistics is an extremely small shut down time. These times were $61^{h}14^{m}$(1982), $120^{h}10^{m}$(1983). Main troubles in recent 5 years which made a cease more than 12 hours are as follows;

1. Discharge at ionizer and deterioration of cooling tube at dissociator in polarized ion source
2. Interphase-short at arc extinguish chambers of the high voltage air circuit breaker for anode power supply.
3. Damage of damper resistance at main amplifier of RF system.
4. Break of warm gear of an induction regulator at the anode power supply.
5. Deterioration of the current limiting reactors at the anode power supply.
6. Cease of bearing of pressurised pump of demineralised water.

Table 3

Account of cyclotron operation (1983)

Beam time for experiments	$4332^h 55^m$
Tuning of beam for experiments	493 15
Development	243 50
Scheduled maintenence and experimental set up	1298 50
Unscheduled shut down	129 10

Table 4

Accelerated particles (1983)

p	$885^h 30^m$
d	35 15
$\vec{p}$	1782 55
$\vec{d}$	515 00
^3He	365 00
	516 40
^6Li	235 25
^7Li	62 05
^{12}C	122 35
^{13}C	89 45
^{14}N	222 15
^{20}Ne	210 30
^{40}Ar	57 05

ACCELERATOR DEVELOPMENTS

Many improvements and better performance of accelerator beam have been done during these experimental period. The beam time shared to these developement is about 15% of total beam time anually.

(i) Raise of maximum energy of proton and ^3He

Due to the result of our measured magnetic field of the cyclotron, vertical focussing limits a maximum proton energy at about 80 MeV. Another difficulties is in several components when the system is operated in a higher frequency or higher dee voltage near design limit. The 85 MeV-protons have been successfully accelerated and extracted. In this case, to overcome the lower dee voltage than that required to maintain constant turn number, the position of the ion source and the puller has been moved slightly toward the machine center to coincide it with the acceleration center under the condition of the lower dee voltage. The turn number has been increased and extraction efficiency has become 37%.

In the case of ^3He, the extraction has been main difficulty. The highest deflector voltage is needed for the extraction of the ^3He beam with the energy of higher than 160 MeV. So far, the highest energy was 150 MeV. Moreover, as the saturation of the magnet iron varies the beam course, the curvature of the deflector can not fit the extracting beam course such the high magnetic field level. The exit position of the second deflector has been also moved to extract the beams.

Another try has been made to accelerate 70 MeV deuteron. There are no problem except deflector voltage. Extraction efficiency is about 50%.

(ii) Better energy and time resulution of the beam

Smallest and stable time width of beam is desirable to measure a time of flight of particle produced in nuclear reaction, especially, neutron. Our method is established with the phase slit and the trim coil current shifting. When a phase slit is installed at a certain radius, the time structure of beam respecting to the rf phase is devided into two even with the same energy. The magnetic field is shifted slightly from the isochronous field by changing one of the inner trim coil current to produce the phase excurtion of the beam. Adjusting the trim coil current one can make a condition that one of the beam pulse remains in an accelerating phase and the other in a decelerating phase. A beam pulse width is restricted to 2~3 ns by this procedure. To get a narrower beam pulse width, the magnetic field has to be shifted further to make a condition that only a part of the beam remains in an accelerating RF phase. In this way, a beam pulse width as narrow as 0.5 ns was obtained. In order to use RAIDEN (a high resolution spectrograph) it is absolutely essential to get a high intense of a beam with better energy resolution. In this case, it is extremely effective for better energy resolution to use asmall ion source exit slit, about 0.4mm. Energy width about 7 keV FWHM was obtained for 55 MeV proton elastic scattering though the beam intensity become finer. In recent days, moderate resolution and high transport efficiency was obtained employing the same method as the beam time width narrowng method. It becomes 10^{-4} after analyzing mag. with 15~20% transport efficiency.

POLARIZED ION SOURCE

Better performance of polarized beam intensity and its stability. The RCNP polarized ion source is an atomic beam type. The schematic diagram of the ion source is shown in Fig. 2. The 1st polarized beam was accelerated in 1975. Some improvements was done in 1984. The ionizer was replaced by new one made by ANAC. Following improvements were done with this replacement; i) introduction of dyflon coolant at dissociator. ii) A cryopump with a pumping speed of 1000 l/s for hydrogen and 2100 l/s for water was introduced near ionizer, iii) Diffusion oil was replaced by Fomblin Y-18/8 not to hydrogenize (iv) microcomputer was introduced to control several power supplies for fine tuning. After these imporvements, the polarization of the extracted protons is above 80% which is 5~10% higher than the previous one. The beam intensity is increased by a factor of 3~5 as compared with previous value. A comparison of these performance is shown in Table 5.

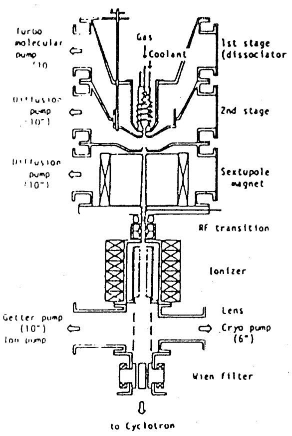

Fig. 2. Schematic diagram of the RCNP atomic beam polarized ion source.

Table 5

The comparison between the previous and the new ionizer

			Beam intensity				
			ion source	at mirror	ext.	(ext_{eff})	beam polarization
old ionizer		p	3~5	1	0,1	100	65~65%
		d			0,07	70	
new ionazer	test	p	10	3	0,25	100	50%
	exp	p	20~30	5 10	0.5~1.0	100	80%
		d			0.3~0.6	70	60~65%

The H^+ and D^+ ion beams are polarized in the vertical direction defined by the magnetic field of the ionizer. The spin directioncan be rotated to the horizontal direction by a Wien filter installed down stream the ion source. The rotation angle α_{rot} of the spin in the Wien filter is checked by measuring the left-right asymmetry for th elastic scattering of the vector polarized beam from ^{12}C. The vertical component Pv of the polarizatin is related to the rotation angle α_{rot} by the equation

$$P_v = P_0 \cos\alpha_{rot}$$

where P_0 is the initial beam polarization. Fig. 3 shows the vertical component of the vector polarization of the accelerated deuteron beam as a functin of the magnetic field of the Wien filter.

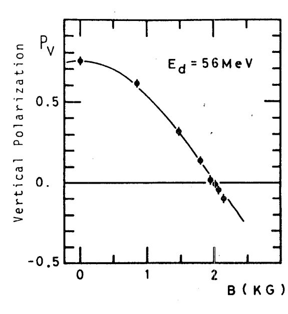

Fig. 3. Vertical polarization of deuteron as a function of the magnetic field of the Wien filter.

ACCELERATION OF THE HORIZONTALLY POLARIZED BEAM

When horizontally polarized beam is accelerated by the cyclotron, the spin precesses around the vertical magnetic field.[3] If a single turn extraction is achieved and the turn numbers of the beam are kept constant, the extracted beam will have the dèfinite polarization with its axis in horizontal plane. However it is not easy to realize a single turn extraction by a cyclotron. Even in the condition of multiturn extraction, the distinction of the turn numbers makes it possible to determine the spin precesion angle (α_{prec}) for each turn. In order to observe the distribution of the turn numbers of the extracted beam, a beam pulsing sytem was employed in the injection system. The distinction of the turn numbers was made by means of the time of flight method. Fig. 4 shows an example of the distribution of ions having various turn nubmers observed by the plastic scintillator for 56 MeV deuterons at a duty cycle of 1/115.

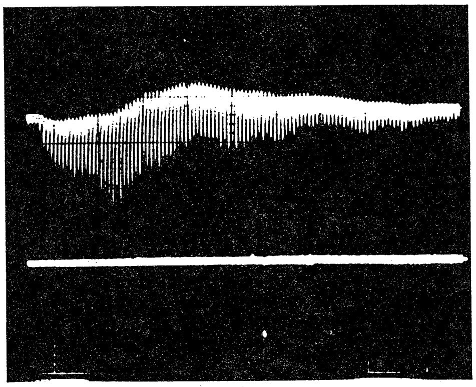

Fig. 4. Distribution of the turn numbers at a duty cycle of 1/115 observed for 56 MeV deuterons. The upper curve indicates signals from the plastic scintillator in the beam path, and the lower curve shows the trigger signal from the frequency divider. The horizontal scale is 1 μs/division.

The distribution of these turn numbers could be resticted by using a phase defining slit in the central region of the cyclotron. When the dee voltage was increased by about 0.2%, the turn number was decreased by one. This value is consistent with about 500 turn numbers of the acceleration up to the outer most radius. In this way we can control the turn numbers of the extracted beam by adjusting the dee voltage. The relation between the turn number and the spin precession angle was investigated by measuring the up-down assymmetry for the elastic scattering of vector polarize deuterons and protons from ^{12}C. Fig. 5 and 6 show the reuslt of the horizontal polarization P_H for 65 MeV protons and 56 MeV deuterons.

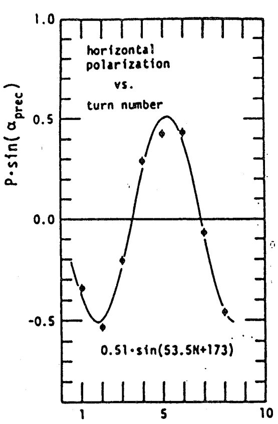

Fig. 5 Horizontal polarization as a functin of the peak number in the TAC spectrum for 65 MeV protons.

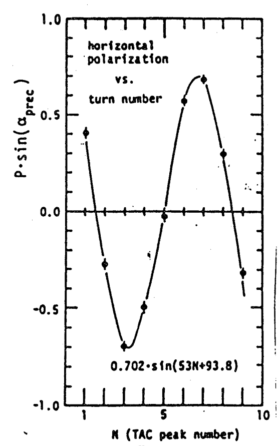

Fig. 6 Same as fig. 5. but for 56 MeV deuterons. The polarization is represented as a ratio to the ideal value, 2/3.

HEAVY ION SOURCE AND HEAVY ION ACCELERATION

A cold cathode, heat insulated PIG source for heavy ions has been developed to get stable arc and long life time.

The original DC arc power supply was replaced with a pulsed power supply to get higher charge state.[4] This delivers rectangular pulsed arc current with variable repetition rate and duty factor superposed to DC current. Using this power supply, we can get almost sufficient intensity and stability of life for $^{20}Ne^{6+}$, $^{12}C^{5+}$ and $^{6}Li^{3+}$. For example, we got 500 nA, 50 nA, 300 500 nA for extracted $^{20}Ne^{6+}$, $^{12}C^{5+}$ and $^{6}Li^{3+}$ ions respectively. Metal ions have been accelerated by back-bombarding method.[5,6] A LiF single crystal is placed into the anode bore as a source element to accelerate $^{6}Li^{3+}$ ions. Xe gas mixed with N_2 is used as a discharge and/or a sputtering gas. It is relatively stable if we set minutely dee voltage and puller and ion source position seeing the increase of dee voltage ripple appeared at dee voltage stabilizer circuits. In 1983, 1/4 of heavy ion machine time was to supply ^{6}Li or ^{7}Li ions. The life time of the ion source is limited to about 10 hours due to cathode life by heavy ion sperttering.

Moreover we have been collecting the fundamental data to understand the elemental characteristics of PIG source, with a test stand. We focussed to develop the higher intensity of $^{40}Ar^{8+}$ ions and to extend the source life time at $^{20}Ne^{6+}$ acceleration.

ANOTHER DEVELOPMENTS AND IMPROVEMENTS

Another main improvements are as follows;

i) Field measurement main magnet with Hall prove
ii) Long term stability of the main magnet field by the replacement of operational amplifiers
iii) Movable phase probe and non-intercepting phase probe
iv) New ^{3}He-gas recirculation system
v) The display of the ion source and puller positions
vi) Replacement of O-ring by helicoflex or conflat flange in beam ducts
vii) NMR stabilizing circuits for A-1 magnetic field.

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