STATUS OF THE RCNP AVF CYCLOTRON

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Abstract

The RCNP AVF cyclotron has been in operation since 1974. The cyclotron beams of different kinds of particles have been used for nuclear research by inside and outside users. Light ions, for example protons up to 75 MeV and α particles up to 120 MeV, have been frequently accelerated. Polarized protons and deuterons have been extracted from the cyclotron with currents of about 100 nA. Heavy ions produced by a modified cold cathod PIG source have been succesfully accelerated in both the fundamental mode and the third harmonic mode. Some results of the developments of the cyclotron are reported.

1. Introduction

The design study with some models for the RCNP AVF cyclotron was started in 1965 based on the recommendation to the Japanese Government by the Scientific Coucil of Japan. The actual design and construction were started in 1970 though the RCNP was established in 1971. The first internal beam was obtained in July 1974 and the extracted beam was transported to the experimental area in August 1975[1]. Tests of operation for the use of nuclear research were made in 1976 together with outside users. The machine was open to outside users in January 1977. About one hundred persons outside the RCNP came to do their experiments in a year. A general layout of the machine and the experimental area is shown in fig. 1. The characteristics of the RCNP AVF cyclotron are listed in table 1.

2. Operation

The regular maintenance of the machine has been scheduled every Monday. The cyclotron has been in operation on the regular schedule of 4 to 5 × 24 hours/week. About one day a week the accelerator has been operated to improve the equipments. A long time shut-down for the maintenance has been scheduled in August every year. Unscheduled shut-down during first year of the regular operation was less than 10 % of the scheduled machine time. Operational time distribution in 1977 are listed in table 2. In normal operation other than polarized beam even one technical staff is able to start up the accelerator and the beam transport system. One can change the beam energy within 30 minutes. Up to now the polarized ion source has been developed and operated by the constructing group. The typical accelerated beams in 1977 are listed in table 3.

3. Light Ions

It is easy to accelerate protons more than 100 μA. But the beam intensity of light ions has been restirictedly operated less than 5 μA in the cyclotron to avoid the radiation damage and to reduce the residual activity. It is sufficient for usual experiments. Many developments have been made to improve the beam qualities. Typically achieved beam qualities are listed in table 3. Details of beam diagonistics will be reported elswhere in this conference[2]. A ^{3}He recovery and purification system works well though a little troubles were sometimes caused by small leaks in a mechanical booster and a rotary pump.

4. Heavy Ions

A so-called "heat-insulated" cathode PIG ion source[12] which is a modified cold cathode PIG source has worked very well. The by-pass gass route for initial discharge is not used now. In operation of ^{14}N beam the life of the cathode is longer than 20 hours. The $^{14}N^{4+}$ beam has been usually accelerated more than 5 eμA. The ^{20}Ne beam has been succesfully accelerated in the third harmonic mode. To prevent undesirable beams a tantalum plate has been installed behind the puller. Details of the heavy ion source will be reported elswhere in this conference[3].

5. Polarized Ions

The polarized ion source was designed and constructed by the Kyoto group[4],[5]. The intensity of the extracted beam has been achieved up to 100 nA with a RF buncher installed in an injection system. In usual experiments the proton beam polarization has been estimated to be about 70 %. The preliminary acceleration was made for the polarized deuterons and the vector polarization of the deuteron beam has been estimated to be about 50 %. The beam polarization is able to be reversed its sign by changing the sign of the coil current of the ionizer solenoid. But, when the sign of the current is changed the beam intensity and direction have been slightly changed. This will be avoidable using a more sophisticated RF transition which will be applied in the near future.

6. Extraction and Beam Transport

Typical extracted beams are listed in table 3. Extraction efficiency of protons has been obtained better than 90 % using a phase slit at the central region. The efficiency for alpha particles at the maximum energy without the phase slit is 50 % or less. This may be explained by the changes of the magnetic field distributions at different field levels because of a saturation effect in a magnet iron. The electrostatic deflector has been designed to extract the beams at moderate field levels. At the highest field level, however, a local curvature of the beam orbit is different. Therefore, positions of the two separated electrodes of the deflector are changed to be placed along the beam orbit in the case of highest energy acceleration other than protons. But the curvature of each electrode could not be changed. The extraction efficiency for heavy ions is about 40 % in the fundamental mode acceleration but is decreases to 20 % in the third harmonic mode. The reasons of the less efficient extraction are considered as the followings. The turn separation of the heavy ion is not so good in the cyclotron because the slit of the ion source is very large to increase the beam intensity. The spurious beam seems to remain in the cyclotron. And usually the heavy ions are accelerated at the high field levels.

Using a large scattering chamber[13] and a few sets of commercial Si surface barrier detectors the energy resolutions have been measured for elastic scattering of each projectiles by a mylar or a gold foil. The observed resolutions are listed in table 4.[14] Beam current up to 100 nA was easily obtained at the target in a dispersive mode and higher current more than 1 μA was transmitted in an achromatic mode. Typical transmission of the beam transport system with an energy resolution of

4×10^{-4} has been obtained to be about 10 % of the extracted beam. In the achromatic mode the transmission has been obtained more than 50 % of the extracted beam. In much dispersive mode of the beam transportation to a large magnetic spectrograph the energy resolution has been observed to be better than 2×10^{-4}. Because an energy defining slit of small width of 0.25 mm has been used in the beam transport system, the transmission in this case has been 0.5 to 1 % depending on the position of the phase slit, dee voltage, and other conditions of the cyclotron. The intensity on the target in such dispersive mode has been 10 to 30 nA. Typical spectrum observed by the spectrograph "RAIDEN"[6] is shown in fig. 2. The polarization of the beam has been estimated by the measurements of the asymmetries in the scattering by ^{12}C. The maximum asymmetry of 73.5 % was observed for p-C elastic scattering at E_p = 65 MeV and θ_{lab} = 47.5°.[15] The intensity of the polarized beam on a target has been 20 to 50 nA in the achromatic mode.

7. Future Improvements

It is planned to construct a new phase slit and probes for the beam diagonistics to improve the beam equality. Beam pulsing elements at the beam line or in the cyclotron are now preliminarily studied. A test bench of a polarized ion source are now under construction to improve its beam intensity. A computer control system has been developed. Up to now the currents of many coils of the accelerator are able to be set by a computer PDP11/40 though the computer setting are not used in the usual operation. The ability of the computer control will be improved in the near future. Details will be reported elswhere in this conference[7].

Future accelerators have been discussed at the RCNP, for example a tandem injector[8], a superconducting cyclotron, a booster ring cyclotron[9], a new big ring accelerator etc.[10],[11]

8. References

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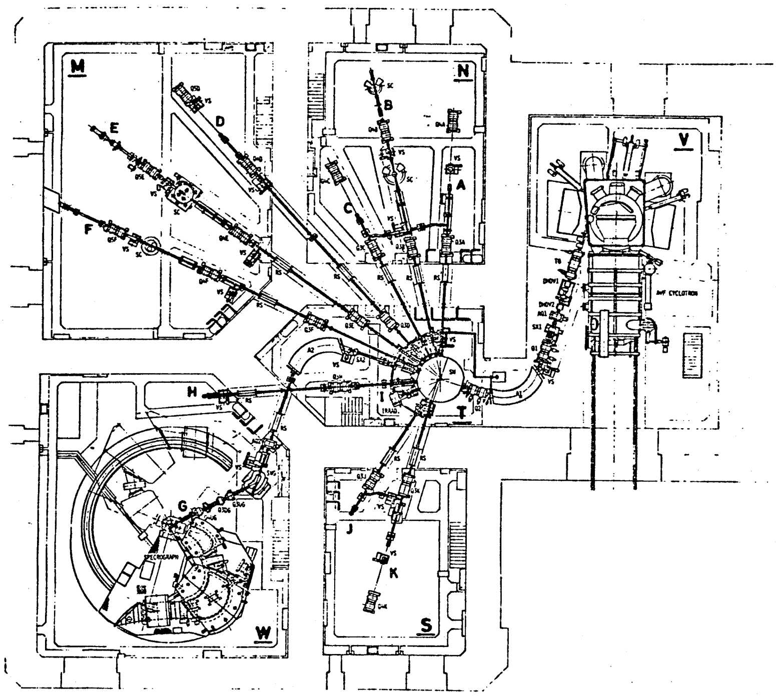

Fig. 1. Layout of the experimental area, beam line and experimental apparatuses including a magnetic spectrograph.

Table 1. Characteristics of the RCNP AVF Cyclotron

MAGNET

POLE FACE dia 230 cm, R ext 100 cm

GAP, min 20.7 cm; Field 19.5 kG
max 34.7 cm; Field 12.0 kG } at 0.4×10^{6} A-turns
AVF FIELD at R max 16.0 kG

CURRENT, STABILITY ± 10 parts/10^{6}

AVF SECTORS 3 SPIRAL, max 52 deg

WEIGHT, Fe 400, Cu 13 tons

POWER, main coils 450, pole tips 265
total 715 kW; cooled by H_2O

ION SOURCE, int Oak Ridge type & Penning
ext Polarized p and d

EXTRACT System dc electrostatic with magnetic channel and electromagnetic focus element

ACCELERATION SYSTEM

DEES, number 1 , width 180 deg

BEAM APERTURE 4.4 cm; DC BIAS 0 kV

RF POWER input, max 430 kW

RF 6 to 18 MHz, stable ± 0.005 /10^{6}

DEE-Gnd, max 80 kV

STABILITY, (pk-pk noise)/(pk RF volt) 1×10^{-4}

CHARACTERISTICS BEAMS

	Particle	Goal	Achieved
		(MeV)	(MeV)
ENERGY	p	≤ 75	75
	d	≤ 60	60
	α	≤ 120	120
CURRENT		(μA)	(μA)
Internal	p	500	≥ 50
	α	200	≥ 50
External	p		≥ 20
	d		≥ 20
	α		≥ 20
			(MeV)
HEAVIEST ion	^{40}Ar	$E = 120\, q^2/A$	196

Table 2. Time distribution in 1977

	hr
experimental use	2653.5
internal beam	576.25
beam cource test	551.0
on beam total	3780.75
maintenance	1167.5
unscheduled shut down	264.0
regular shut down except cyclotron maintemance	3547.75
off beam total	4979.25
total (365 d)	8760.0

Unscheduled shut down	hr
Ion sources including injection and gas system	89.25
Central electrodes	54.0
Deflector	39.75
Probes	27
RF power supplies	25.5
Magnet power supplies	13.5
Cooling and others	8.25
Beam transport system	6.75
	264

Table 3. Accelerated particles in 1977

	MeV	hr
p	40 ∿ 75	861.75
d	55	135.5
α	30 ∿ 120	663.5
^{3}He	70 ∿ 140	1129.0
$\vec{p}$	45 ∿ 68	506.75
H_3^{1+}	11*	5.5
^{14}N	130 , 210	326.0
^{12}C	160	8.5
^{16}O	180 , 260	12.75
^{20}Ne	90*∿ 216	122.5
^{40}Ar	110*∿ 196*	9.0
		3780.75

*3rd harmonic acceleration

BEAM PROPERTIES

	Measured	Conditions
Pulse width	∿ 7° RF deg	1∿2 μA of 90 MeV α
Phase Exc,	max∿5° RF deg	1∿2 μA of 90 MeV α
Extract Eff	∿ 90 %	1∿2 μA of 65 MeV p
Res, $\Delta E/E$	∿ 0.1 %	1∿2 μA of 90 MeV α
Emittance (mm-mrad)	10 axial, 20 radial	1∿2 μA of 90 MeV α

VACUUM norm 1 μtorr; PUMPDOWN time 1 hr

Polarized deuterons were accelerated in January 1978

Table 4. Energy resolutions of several particles elastically scattered by a mylar and a gold foil.[14]

Incident particle	Incident Energy (Mev)	Target and Thickness		Resolution (keV)	Beam spread, etc. (keV)
p	30	Mylar	1.0 mg/cm^2	61 (for ^{16}O)	18
d	50	Au	0.2	50	33
^{3}He	110	Au	0.2	60	36
^{3}He*	110	Au	0.2	190	184
^{4}He	108	Au	0.2	75	51
^{14}N	115	Au	0.2	217	76
^{20}Ne	150	Au	0.2	440	-

* Achromatic beam

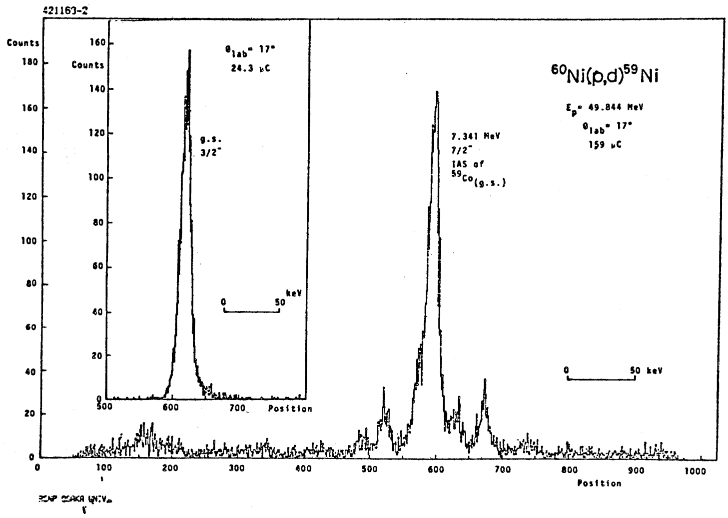

Fig. 2. Spectrum for the ^{60}Ni(p, d)^{59}Ni reaction at θ_{lab} = 17° observed by the magnet spectrograph "RAIDEN".[6]