PROPOSAL FOR A NEW RING ACCELERATOR

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Abstract

An intermediate energy particle accelerator complex is being designed for the next project of RCNP. This accelerator complex covers a wide energy range above the RCNP cyclotron beams and accelerates ions from proton through uranium with high intensity and good beam quality. Protons of 550 MeV are available for the Meson Factory. The main accelerator is divided into two separated-sector ring cyclotrons to keep away from the ν_z=1 resonance. An ordinary AVF cyclotron and a Wideroe type variable frequency linac will be used for light ion and heavy ion injection respectively.

Introduction

A proposal for an intermediate energy particle accelerator complex was presented to the Symposium for Studies of Future Plan of RCNP[1)2)]. The design of this accelerator has been refined recently.

A number of separated-sector cyclotron facilities have been proposed and some of them are completed successfully. However it was difficult to design a variable energy and variable particle separated-sector cyclotron which can accelerate protons up to 500 MeV without crossing ν_z=1 resonance. This difficulty is overcome with a new design.

The proposed facility consists of two separated-sector cyclotrons which are not identical, an ordinary AVF cyclotron (light ion injector) and a Wideröe type variable frequency linac (heavy ion injector).

The construction period of the accelerator complex can be divided into three phases. On the phase 1, an injector cyclotron (K=70, K_f=30, R_{ex}=0.65m) and the first ring (Ring No. 1: N=4, R_{inj}=1.35m, K_{inj}=30, K=230, R_{ex}=3.4m) will provide energies up to 190 MeV and 56 MeV/amu for protons and light ions, respectively. The second ring (Ring No. 2: N=8, R_{inj}=3.4m, K=460, R_{ex}=4.7m) is added on the phase 2, and the energy range will be extended up to 550 MeV and 118 MeV/amu for protons and light ions respectively. Finally, an injector heavy ion linac (0.5MV C.W. + 20MV + 18MV) will increase the energies and intensities of the heavy ions. Uranium ions will be accelerated up to 12.6 MeV/amu. Fig. 1 shows the expected maximum energies in phases 1, 2 and 3 compared with those of several other major projects.

A super-conducting cyclotron especially designed for low q/A value particles can be used as an alternative to the injector linac, without adding any difficulties.

Table I. Characteristics of accelerators

	INJECTOR CYCLOTRON	RING 1	RING 2
No. OF MAGNETIC SECTOR	4	4	8
MAGNET FRACTION	1.0	0.37	∿ 0.42
SECTOR ANGLE		33°	∿ 19°
INJECTION RADIUS		1.3 m	3.4 m
EXTRACTION RADIUS	0.65 m	3.4 m	4.7 m
MAGNET GAP	18.5 cm	8 cm	8 cm
MAX. MAGNETIC FIELD	18.5 kG($\bar{B}$)	16 kG	18.3 kG
K-VALUE(INJ) FOR H.I.		30 MeV	230 MeV
K-VALUE(EXT) FOR H.I.	70 MeV	230 MeV	460 MeV
MAGNET WEIGHT	160 Ton	1200 Ton	1600 Ton
MAIN COIL POWER	200 kW	400 kW	600 kW
No. OF TRIMMING COILS	5	30	60
TRIMMING COIL POWER	20 kW	150 kW	200 kW
No. OF CAVITY	2	2	4
RF FREQUENCY	20 ∿ 32 MHz (10 ∿ 32)MHz	20 ∿ 32 MHz	20 ∿ 32 MHz
MAXIMUM VOLTAGE	50 kV	400 kV	500 kV
RF POWER	30 kW × 2	150 kW × 2	200 kW × 4
	COCKCROFT-WALTON	LINAC # 1	LINAC # 2
ACCELERATION VOLTAGE	0.5 MV	20 MV	18 MV
RF FREQUENCY		20 ∿ 32 MHz	20 ∿ 32 MHz
RF POWER(CW)		150 kW × 3	200 kW × 3

The main accelerator

The main accelerator is divided into two separated-sector ring cyclotrons to keep away from the ν_z=1 resonance. The two ring magnets weigh less together than a single ring system[3)].

The plan view of the ring No. 1 and the ring No. 2 is shown in Fig. 2. The ring magnets have 8 cm gaps and Rogowski edges. The ring No. 1 has four 33° radial sectors. The ring No. 2 has eight spiral sectors.

Orbit dynamics of the ring magnets

Orbit properties of the isochronous cyclotron ring

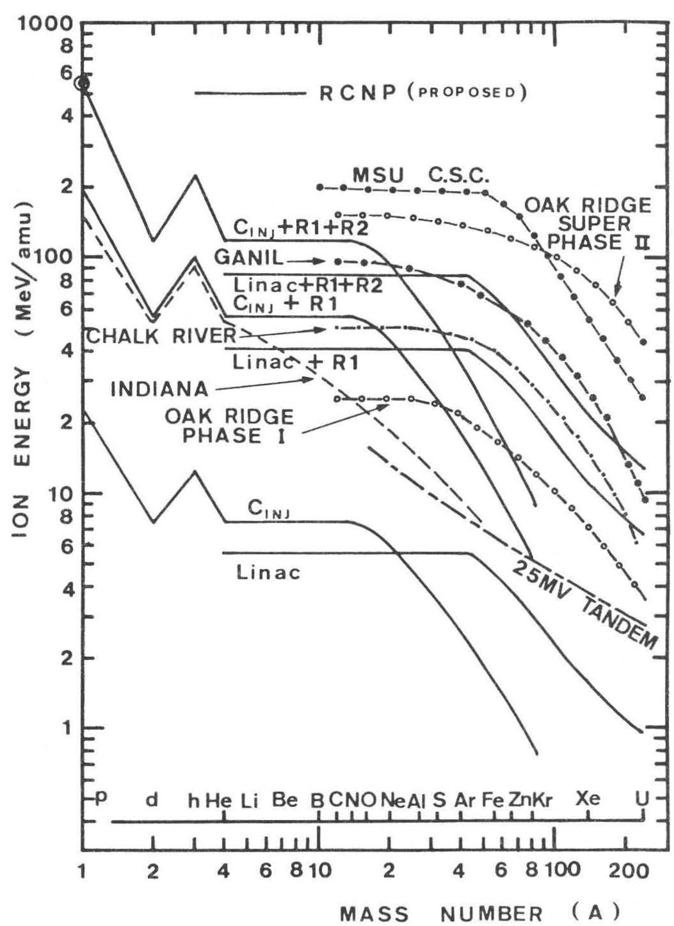

Fig. 1. Expected maximum energies of various ions for this proposal and several major projects.

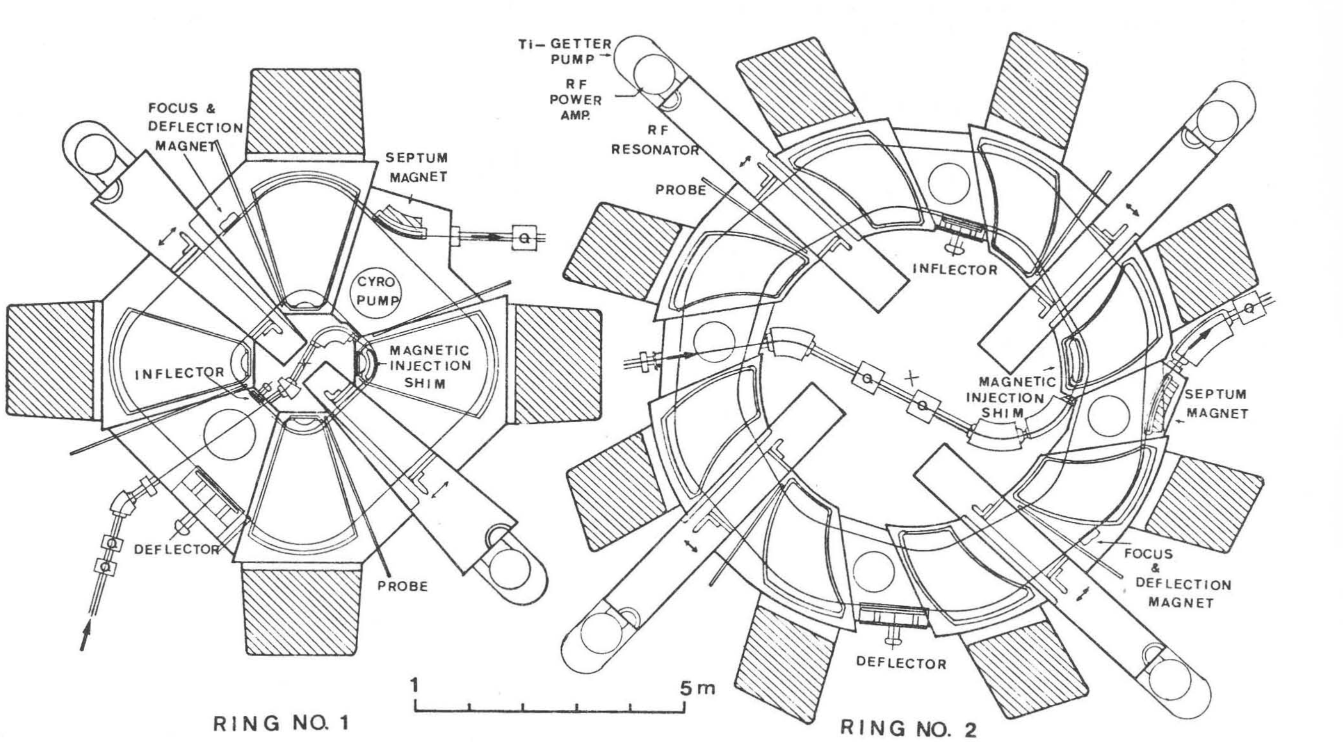

Fig. 2. Plan view of the ring No. 1 and the ring No. 2.

can be computed easily with the Spy-Ring Code[4,5] using the hard-edge approximation. However there is a considerable deviation in the prediction of the axial focusing frequency, especially for small radius and large gap magnet.

The Spy-Ring Code was modified to account for the soft edge effect at the effective field boundaries and the effective angles of incidence[6]. The radial and axial focusing frequencies calculated with the modified Spy-Ring Code are shown in Fig. 3 with the results of the OAK RIDGE PHASE II model study[7]. The modified Spy-Ring Code predicts precisely the radial and axial focusing frequencies for the radii on which the valley width is wider than 10 magnet gaps. For small radii of this magnet, a correction for the considerable fringing-field overlapping must be made.

The modified Spy-Ring Code was used throughout the design of this proposal. The radial and axial focusing frequencies of the ring No. 1 and the ring No. 2 are calculated with the modified Spy-Ring Code for various ions and shown in Figs. 4 and 5, respectively. No correction is necessary for the fringing-field overlapping, since the valley width of the ring No. 1 is wider than 15 magnet gaps. Ions from proton through uranium can be accelerated without crossing the $\nu_z=1$ resonance.

The isochronous hill fields for various ions are shown in Fig. 6. The ring No. 2 is almost isochronous for 660 MeV $^3He^{2+}$ without trimming current.

The maximum field of the ring magnets is 16kG except for $\sim$500 MeV proton. The field at the extraction radius is 18.3kG for 550 MeV proton. The maximum flux density in yoke is 15.5kG. The model magnet study has been undertaken.

Radio frequency system

Variable frequency single gap cavities are proposed for acceleration. The ring No. 1 and the ring No. 2 have 2 and 4 cavities respectively. A common and narrow acceleration frequency range (20$\sim$32 MHz) is used through the accelerator complex. Fig. 7 shows the acceleration harmonics in the two rings for various ions and energies. The maximum acceleration voltages for the ring No. 1 and the ring No. 2 are 0.8 MV/turn and 2 MV/turn respectively. The turn separations at the injection radii are 30mm and 16mm for the ring No. 1 and the ring No. 2 respectively. The turn separations at the extraction radii are 8mm and 5mm for the ring No. 1 and ring No. 2 respectively.

Injection and extraction

A plan view of the injection and extraction systems is also shown in Fig. 2. The injection systems of the ring No. 1 and the ring No. 2 consist of magnetic injection shims (ΔB_{max}=+2kG) and electrostatic inflectors ($E_{inf.R1}$=50 kV/cm, $E_{inf.R2}$=90 kV/cm). The extraction systems of the ring No. 1 and the ring No. 2 consist of electrostatic deflectors ($E_{def.R1}=E_{def.R2}$ =60 kV/cm), septum magnets (B_{max}=16kG) and auxiliary focus-deflection magnets.

Injectors

Injector cyclotron

An ordinary AVF cyclotron will be used for the light ion injection. Since the K-value of the injector cyclotron (K=70) is larger than one of the ring No. 1 at injection radius (K=30), highly stripped light ions can be accelerated in the main accelerator using a gas stripper as shown in Table II.

The transit time effect between the ion source and the puller decreases the extraction efficiency for low q/A value particles. However, increased beams are obtained with the dc extraction for those particles.

Linear accelerator

The heavy ion injector is a Wideröe type variable

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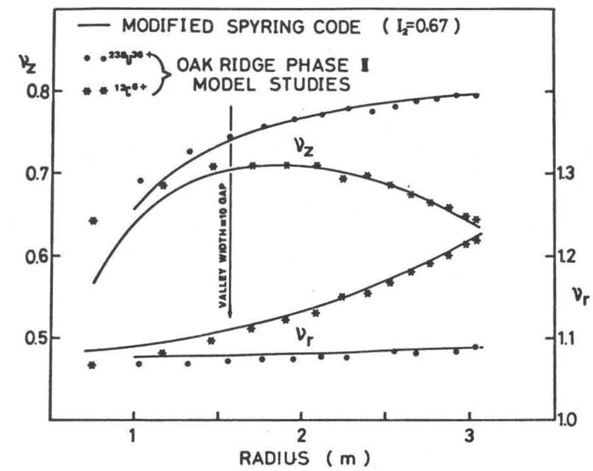

Fig. 3. The radial and axial focusing frequencies calculated with modified Spy-Ring Code and the results of OAK RIDGE PHASE II model magnet study.

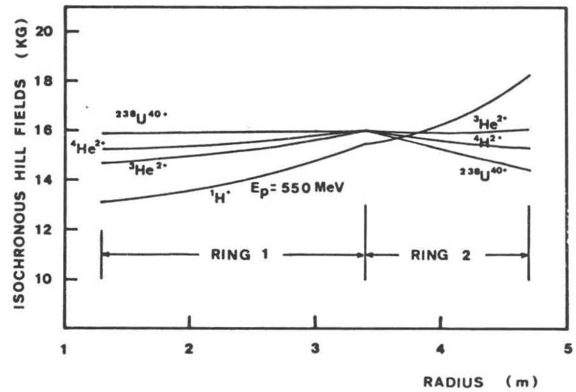

Fig. 6. Isochronous hill field of the ring No. 1 and the ring No. 2 for various ions.

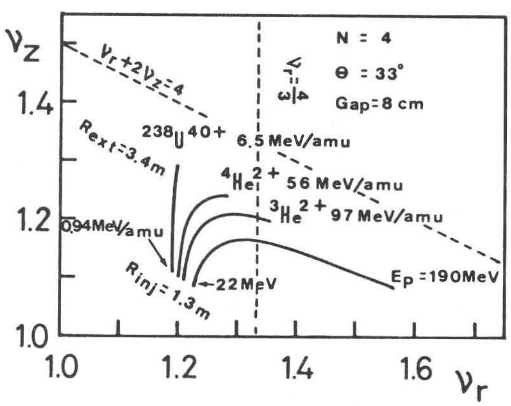

Fig. 4. The radial and axial focusing frequencies for the ring No. 1 calculated with the modified Spy-Ring Code.

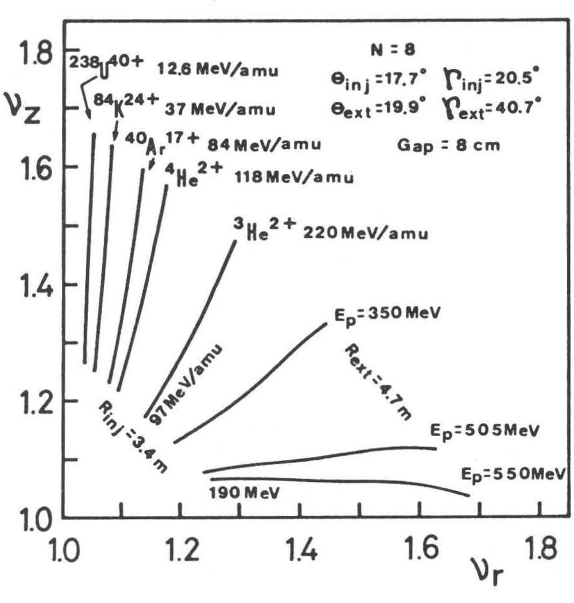

Fig. 5. The radial and axial focusing frequencies for the ring No. 2 calculated with the modified Spy-Ring Code.

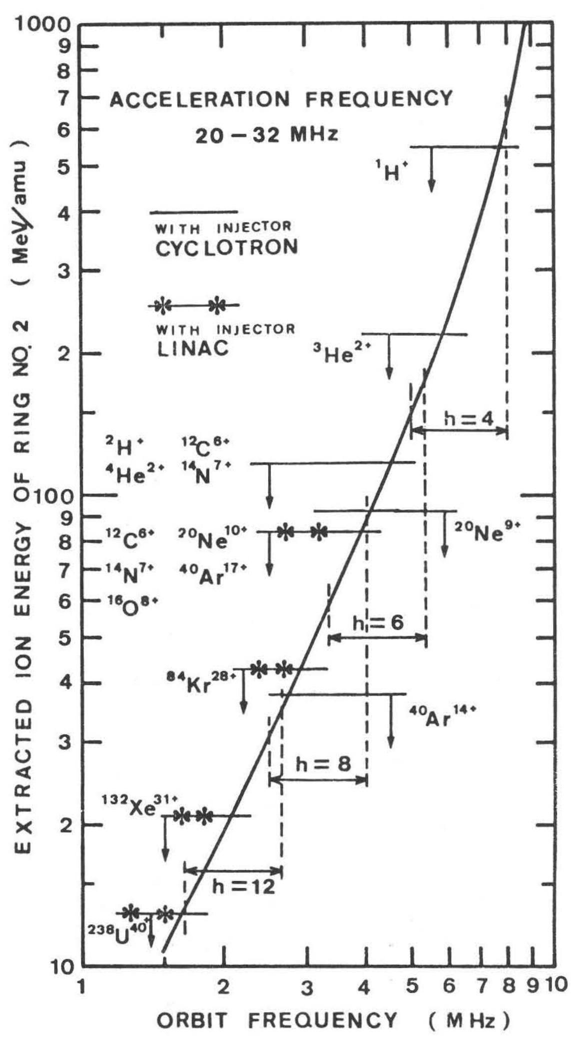

Fig. 7. Acceleration harmonics h in the two rings for various ions and energies.

Table II.

Specification of accelerators (INJ + R1 + R2)

	CHARGE (INJ)	INJECTOR CYCLOTRON(INJ)		CHARGE (R1,R2)	RING CYCLOTRON #1 (R1)			RING CYCLOTRON #2 (R2)				ACCELERATION		
A		B(EXT) kG	E/A(EXT) MeV		B(INJ) kG	B(EXT) kG	E/A(EXT) MeV	B(INJ) kG	B(EXT) kG	E/A(EXT) MeV	I(EXT) pμA	ACC.F MHz	HARMONIC No. (R1,R2)	(INJ)
1 H	1+	10.5	22	1+	13.1	15.5	190	15.5	18.3	550	50	31	4	2
2 H	1+	12.2	7.6	1+	15.2	16.0	56	16.0	15.2	118	30	27.7	6	3
3 He	2+	11.8	12.5	2+	14.7	16.0	97	16.0	16.0	220	20	23.5	4	2
4 He	2+	12.2	7.6	2+	15.2	16.0	56	16.0	15.2	118	20	27.7	6	3
12 C	4+	12.5	3.6	4+	15.6	16.0	25	16.0	14.7	51	2	25.6	8	4(2)*
12 C	3+	12.7	2.05	3+	15.8	16.0	14.3	16.0	14.5	28	2	29	12	6(3)*
40 Ar	8+	12.8	1.33	8+	15.9	16.0	9.2	16.0	14.5	18	(0.1)†	23.5	12	6(3)*
12 C	4+	18.3	7.6	6+G	15.2	16.0	56	16.0	15.2	118	2	27.7	6	3
14 N	5+	17.1	7.6	7+G	15.2	16.0	56	16.0	13.5	118	0.2	27.7	6	3
20 Ne	6+	18.3	6.2	9+G	15.2	16.0	44	16.0	13.2	93	0.2	24.9	6	3
40 Ar	8+	18.3	2.7	14+G	13.0	13.2	19	13.2	13.5	38	(0.1)†	22.2	8	4(2)*

B:MAGNETIC FIELD, E:ENERGY, A:MASS, G:GAS STRIPPER, I:BEAM CURRENT, ACC.F:ACCELERATION FREQUENCY
†:INTERNAL SOURCE WITH DC EXTRACTOR, *:ACC.F OF INJECTOR=10 ∼ 32 MHz.

Table III.

Specification of accelerators (LINAC + R1 + R2)

	CHARGE (CW,L1,L2)	CW (CW)	LINAC (L1)	LINAC (L2)		LINAC	RING CYCLOTRON (R1,R2)			CHARGE (R1,R2)		
A		ACC.V MV	ACC.V MV	ACC.V MV	E/A(L2) MeV	ACC.F MHz	ACC.F MHz	HARM.	B(MAX) kG		E/A(R2) MeV	I(EXT) pμA
12 C	2+	0.36	14.6	18.6	5.6	32	32	8	13.6	6G	84	10
14 N	3+	0.28	11.3	14.5	5.6	32	32	8	13.6	7G	84	10
16 O	3+	0.32	13.0	16.6	5.6	32	32	8	13.6	8G	84	10
20 Ne	4+	0.30	12.1	15.6	5.6	32	32	8	13.6	10G	84	10
40 Ar	7+	0.35	13.9	17.8	5.6	32	32	8	16.0	17F	84	1
84 Kr	8+	0.34	13.7	17.5	3.0	23	23	8	16.0	28F	43	1
132 Xe	10+	0.5	20.0	0	1.55	25	25	12	16.0	31F	21	0.1
238 U	11+	0.5	20.0	0	0.94	20	20	12	16.0	40F	12.6	0.02

CW:COCKCROFT-WALTON, E:ENERGY, A:MASS, ACC.V:ACCELERATION VOLTAGE, ACC.F:ACCELERATION FREQUENCY,
HARM.:HARMONIC No., I:BEAM CURRENT, G:GAS STRIPPER, F:FOIL STRIPPER.

frequency (20∼32 MHz) linac followed by a gas or a foil stripper. The distances between the last two inner drift tubes of the 20 MV and the 18 MV linac sections are 1/12 and 1/8 of the orbit length at the injection radius of the ring No. 1. The energies of the heavy ions will be increased using the injector linac. The beam intensities will be increased since the linac has a large phase acceptance. The specifications of accelerators with the injector cyclotron and the linac are shown in Tables II and III respectively.

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