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DESIGN STUDY OF THE INTERMEDIATE ENERGY PARTICLE ACCELERATOR COMPLEX

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Abstract

An intermediate energy particle accelerator complex has been proposed as a new accelerator facility of RCNP. This variable energy accelerator complex covers a wide energy range above the present RCNP cyclotron and accelerates ions from proton through uranium with high intensity and good beam quality. Protons of 550 MeV are available for a meson factory. The main accelerator is divided into two cascade ring cyclotrons. An ordinary AVF cyclotron and a Wideröe type variable frequency linac will be used as light ion and heavy ion injector, respectively. A 1/3.5 scale model of the 1st ring magnet and a 1/10 scale model of variable frequency single gap acceleration cavities are being studied.

Introduction

The proposed facility[1)2)] consists of two separated-sector cyclotrons, an ordinary AVF cyclotron (light ion injector) and a Wideröe type variable frequency linac (heavy ion injector). A common and narrow acceleration frequency range (20∿32 MHz) is used through the accelerator complex. The characteristics of the cyclotrons are given in Table I.

The construction period of this complex can be divided into three phases. In the phase 1, the injector cyclotron and the first ring will provide energies up to 190 MeV and 56 MeV/amu for protons and light ions, respectively. The second ring is added in 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 the injector linac will increase the energies and intensities of the heavy ions. Uranium ions will be accelerated up to 12.6 MeV/amu. Fig. 1 shows expected maximum energies of this proposal on the phase 1, 2 and 3 with several major projects.

Table I.
Characteristics of the cyclotrons

	INJECTOR CYCLOTRON	1st RING	2nd RING
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	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

Description of the Cascade Ring Cyclotrons

The plan view of the 1st ring and the 2nd ring is shown in Fig. 2. Both the ring magnets have 8 cm gaps and the Rogowski's edges. The 1st ring has four 33° radial sectors. The 2nd ring has eight spiral sectors. Variable frequency single gap cavities are used for accelerations. The maximum acceleration voltages for the 1st ring and the 2nd ring are 0.8 MV/turn and 2 MV/turn, respectively. The turn separations at the extraction radii are 8 mm and 5 mm for the 1st ring and the 2nd ring, respectively. Each injection system of the rings consists of magnetic injection shim (ΔB_{max}=+2kG) and electrostatic inflector ($E_{inf.R1}$ =50 kV/cm, $E_{inf.R2}$=90 KV/cm). Each extraction system of the rings consists of electrostatic deflector ($E_{def.R1}$ = $E_{def.R2}$=60 kV/cm), septum magnet (B_{max}=16 kG) and auxiliary focus-deflection magnet. These parameters and configurations of the cascade ring cyclotrons are chosen after serious consideration on the feasibility.

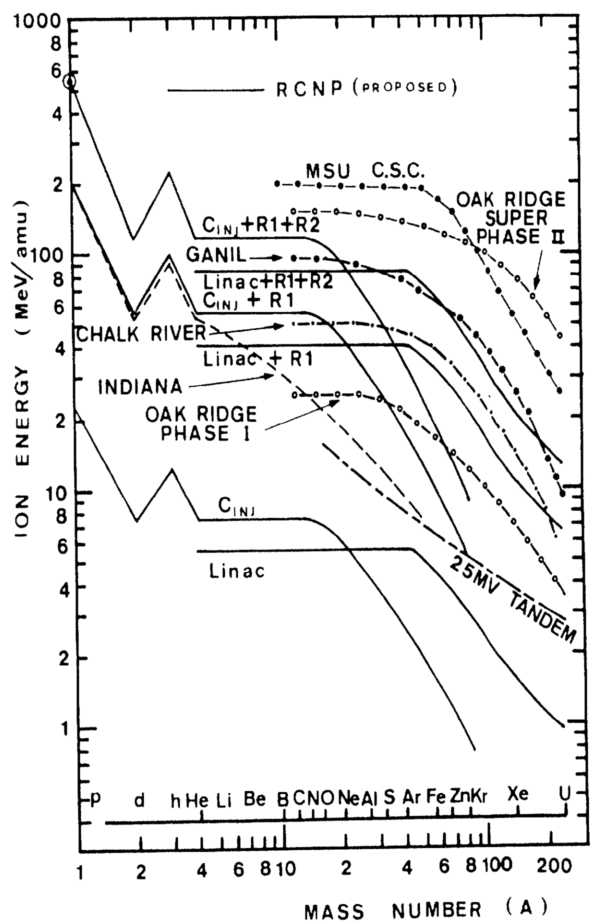

Fig. 1 Expected maximum energies of various ions for this proposal and several major projects. C_{inj} is the injector cyclotron. R1 and R2 are the 1st ring and the 2nd ring, respectively.

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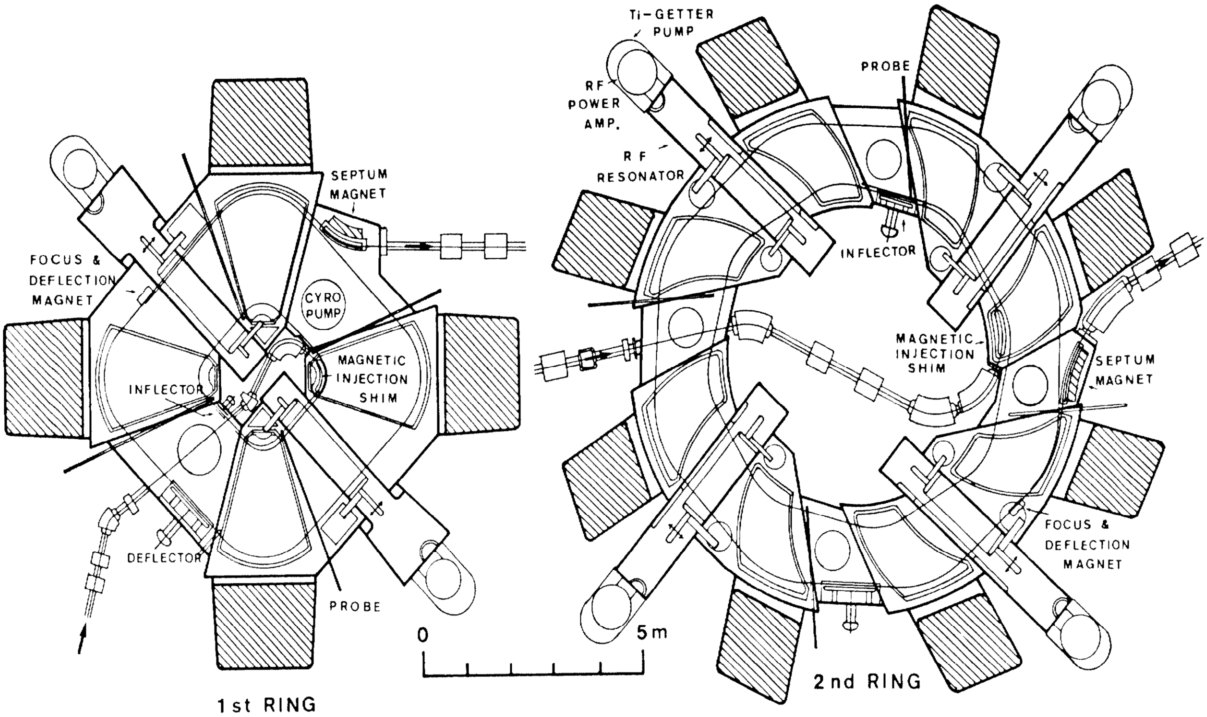

Fig. 2 Plan view of the 1st and the 2nd ring.

Orbit properties of the isochronous cyclotron ring are studied with Spy-Ring Code[3)4)]. This code was modified[2)] to take into account the soft edge effect through the effective field boundaries and the effective angles of incidence[5)]. The modified Spy-Ring Code predicts precisely the radial and axial focusing frequencies for the radii where the valley width is wider than 10 magnet gaps[2)]. The calculated axial focusing frequencies of the 1st ring and the 2nd ring for various ions and energies are larger than 1[2)].

Model Magnet of the Ring Cyclotron

A 1/3.5 scale model magnet of the 1st ring is prepared to study various magnetic field properties. The model magnet, weighing about 8 tons, is shown in Fig. 3. The pole pieces are made of low carbon(0.04%) forged iron. The yoke is divided into 3 pieces. Each piece of yoke is low carbon(0.01%) casted iron degassed before casting. The radial pole edges are shaped stepwise into a Rogowski's curve with a numerically controlled milling machine. All these fabrication processes can be applied for the full scale magnets. Copper ribbon coils are used for the model magnet to reduce cross section of coils.

The roots of the pole pieces are extended from the effective field boundaries half of the gap width to the outside. This extended region is prepared as a guide channel for the magnetic flux around one coil. The inner pole edges are cut to give twice of the magnet gap. The roots of the outer pole edges also have considerable extensions.

A BHT 910 Hall generator is used for the magnetic field measurements. The Hall probe are mounted on an end of an aluminum arm stretched from a probe carriage to the center line of the model magnet.

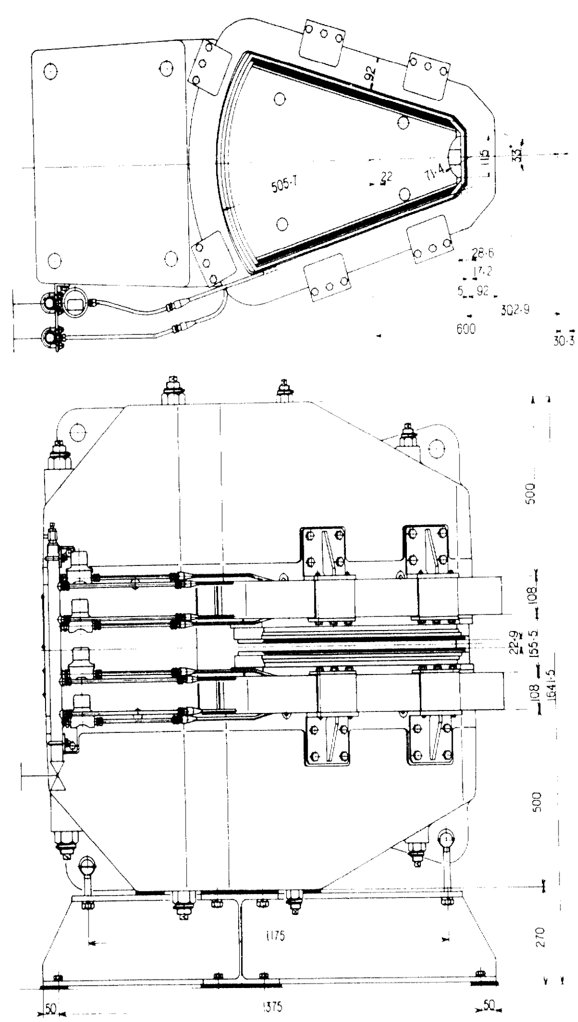

Fig. 3 Plan and side views of a 1/3.5 scale model magnet of the 1st ring cyclotron.

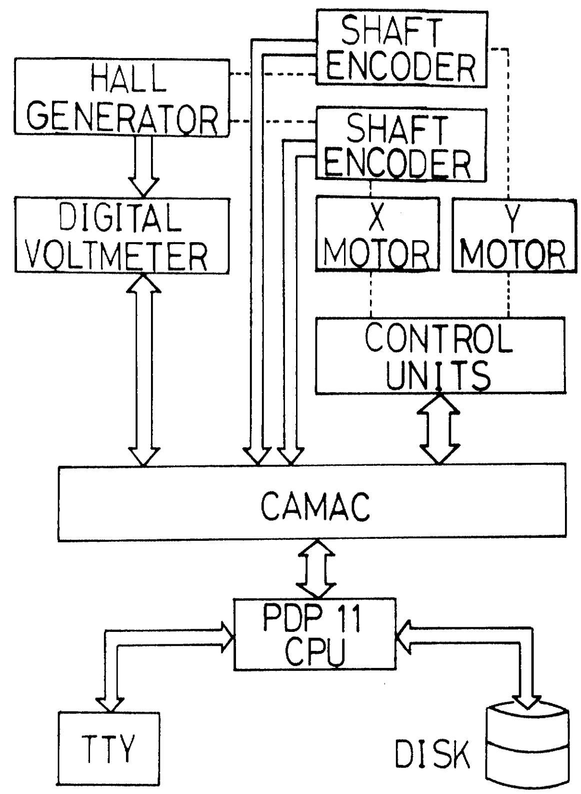

Fig. 4 Schematic diagram for magnetic field measurements.

Magnetic field mapping is performed on a cartesian grid. The probe carriage on cross sliders is driven with ball-screwed spindles (6mm pitch) by directly coupled stepping motors (200 pulse/rev.). The position of the carriage is monitored with optical shaft encoders (200 pulse/rev.) coupled directly to the stepping motors. The magnetic field mapping and the data acquisition, reduction and storage are automatically controlled by PDP 11/10 computer as shown in Fig. 4.

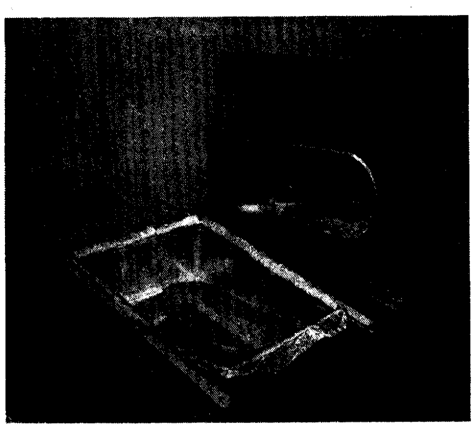

Fig. 5 Photograph of the model cavity of the 1st ring.

1/10 Scale Model of the Single Gap Cavities

A preliminary study of variable frequency single gap cavities for the 1st ring and the 2nd ring was done with 1/10 scale models as shown in Fig. 5. Each model has an oval sliding tuner plate and covers the proposed frequency range of the model (200∿320 MHz). These radially offset single gap cavities produced radially increasing RF voltage as shown in Fig. 6. The compression of the beam phase width[6)7)] can be expected.

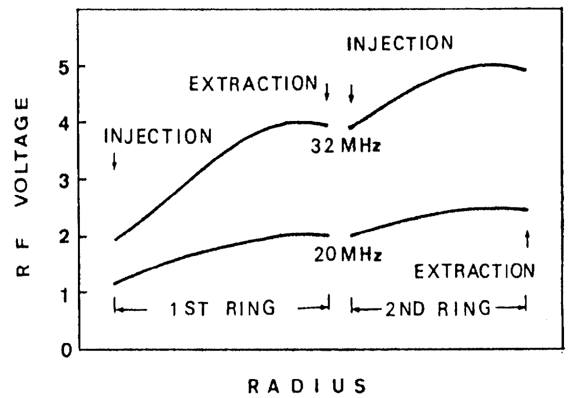

Fig. 6 Measured RF voltage distributions along acceleration gaps.

The single gap acceleration cavities are suitable for this cascade ring cyclotrons, since the valley width are rather wide and the injection radii are large. The acceleration gaps are 14 cm and 15 cm for the 1st ring and the 2nd ring, respectively. GSI group[6)] showed that the practical upper limit of RF field strength for a single gap device is 20 MV/m in clean vacuum. Considering these value, the variable frequency single gap cavities may be operated up to 500 kV (3.3 MV/m) without serious sparking problem.

Acknowledgements

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