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THE RCNP RING CYCLOTRON

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ABSTRACT

In 1986, the Ministry of Education authorized the RCNP cyclotron cascade project to start in the spring of 1987. The main components of the new facility are a six separated spiral sector cyclotron (ring cyclotron) and a beam circulation ring linked to a high precision dual magnetic spectrograph system. The beams extracted from the RCNP AVF cyclotron are transported toward north through one of the beam lines of the present facility and injected into the ring cyclotron. With this ring cyclotron, beams of p, d, ^{3}He, alpha and light-heavy ions will be made available in the wide range of energies of up to 400, 200, 510, 400 and $400 \cdot Q^2/A$ MeV, respectively. An emphasis is placed on the production of high quality beams to enable precise experiments.

INTRODUCTION

The ring cyclotron[1)] is an energy quadrupoler of the present RCNP AVF cyclotron. Injection and extraction radii of the ring cyclotron are 2.0 m and 4.0 m, respectively. The characteristics of the ring cyclotrons are given in Table 1. Figure 1 shows a plan view of the ring cyclotron.

Three single gap acceleration cavities are used in the ring cyclotron. The frequency range of the cavity is 30~52 MHz. Acceleration harmonics of protons and alpha particles are 6 and 10, respectively. An additional single gap cavity is used for flat-topping with third harmonics of the acceleration frequency to get energy resolution better than 10^{-4}.

TABLE 1

Characteristics of the ring cyclotron

Maximum energy	p	400 MeV
	d	200 MeV
	^{3}He	510 MeV
	^{4}He	400 MeV
	light-heavy ions	400 Q^2/A MeV
Magnet	Number of sectors	6
	Sector angle	21.9° ~ 27.5°
	Magnet gap	6 cm
	Maximum field	17.5 kG
	Iron weight	2100 tons
	Main coil power	450 kW
	Number of trim coils	36
	Trim coil power	350 kW
	Injection radius	200 cm
	Extraction radius	400 cm
Acceleration system	Cavity	3(single gap type)
	Frequency range	30 ~ 52 MHz
	Maximum accelerating voltage	500 kV
	RF power	250 kW×3
Flat-topping system	Cavity	1(single gap type)
	Frequency range	90 ~ 155 MHz
	Maximum voltage	170 kV
	RF power	30 kW

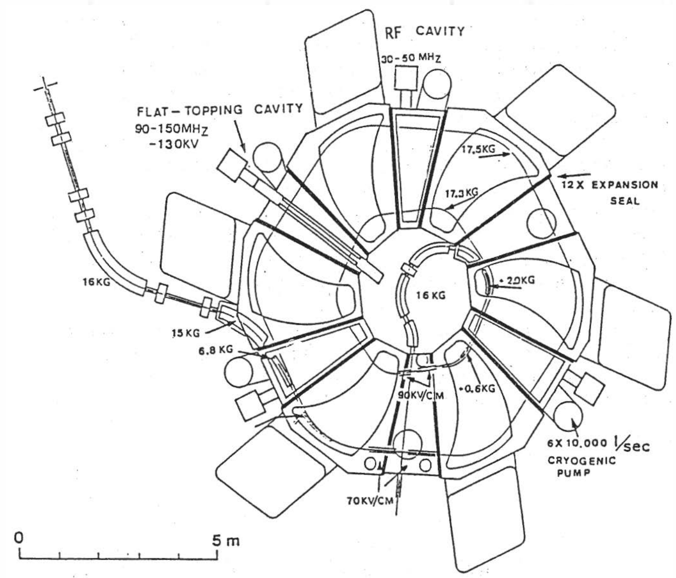

Fig. 1 Plan view of the ring cyclotron

The acceleration chamber of the ring cyclotron consists of 6 magnet chambers, three acceleration cavity chambers, a flat-topping cavity chamber and two valley chambers as shown in Fig. 1. The gaps between these chambers are sealed by using pneumatic expansion seals. The reliability of the seals was verified by the model study of the pneumatic expansion seals.

SECTOR MAGNET

The general design sepecifications of the sector magnet[2)] are outlined as follows. (1) The injection radius is 200 cm because we will use the existing AVF cyclotron as the injector, which has an extraction radius of 100 cm. In order to accelerate protons upto 400 MeV, protons of 65 MeV are injected into the ring cyclotron. (2) In the acceleration, the vertical betatron frequencies (ν_z) for the various ions and energies should be always larger than 1.0. (3) The maximum magnetic flux density of the sector is set to 17.5 kG and the magnetic gap width is 60 mm, in order to reduce the total weight of the magnet.

The six spiral-sector geometry has been adopted on the basis of the above conditions. We calculated the field maps of the various spiral sector magnets in order to get the desired field profiles and the desired orbit properties. Fig. 2 shows the calculated radial and vertical focusing frequencies and the isochronous fields for the maximum energies for various ions. The final parameters of the sector magnet have been determined from the analyses of the magnetic properties and the orbit calculations.

The maximum magnetomotive force is estimated to be 1.4×10^5 ampere-turns for the maximum field of 17.5 kG. The maximum power consumption of the main coils is estimated to be 440 kW. Each sector magnet is about 5.6 m in length and 5.26 m in height. The weight is about 350 tons. The shape and the geometrical size of the sector magnet are shown in Fig. 3.

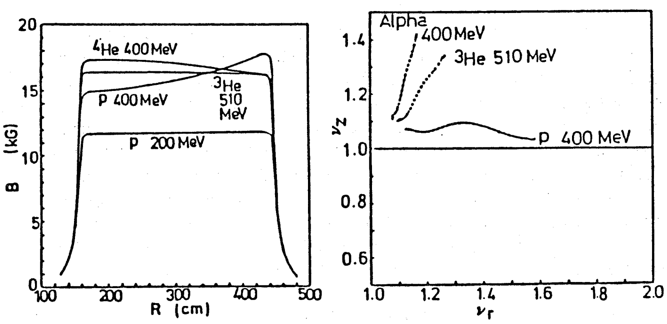

Fig. 2. Calculated radial and vertical focusing frequencies and isochronous fields for the maximum energies for various ions.

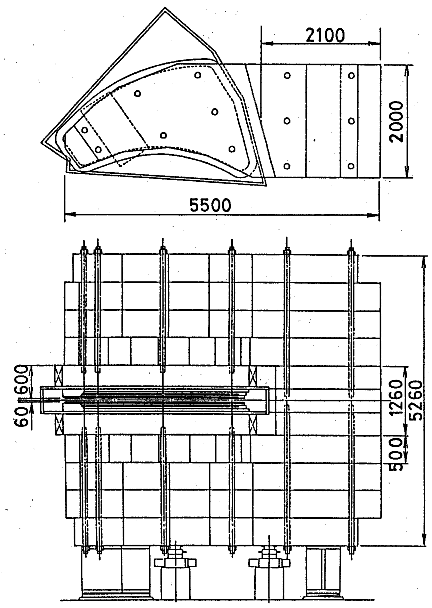

Fig. 3. Shape and geometrical size of the sector magnet.

The upper and lower yokes will be divided into four pieces, respectively. Each piece of the yokes is 500 mm in thickness and will be made of low carbon (~0.02%) rolled iron. The pole pieces will be made of low carbon (~0.005%) forged iron. The radial pole edges are shaped stepwise, which is nearly equal to a Rogowski's curve. The ratio of the cross-sectional area of the yoke to the area of the pole base is about 1.14. The sector angle is 22°~27.5°. Vacuum chamber walls made of SUS are welded at the side faces of the poles.

RF SYSTEM

Three acceleration cavities and one flat-topping cavity are installed between sector magnets[3]. Variable frequency single gap type cavities are to be used for the acceleration cavity. A fiarly well voltage distribution can be obtained with proper choice of radial length of the cavity and shape of acceleration electrodes in the given geometrical condition. Single gap cavity has high acceleration efficiency for any harmonic mode acceleration. New methods to vary the resonance frequency have been investigated. Various studies are now in progress on 1/5 scale model for this cavity.

A single gap cavity is used for the flat-topping cavity. A 1/5 scale model of the single gap flat-topping cavity was made to investigate the RF caracteristics. Fig. 4 shows the model cavity. The cavity has a pair of lips at acceleration gap. The acceleration gap is 50 mm. RF power is fed to the cavity through an inductive power feeder. Resonance freqeuncy is varied by a pair of sliding tuner plates as shown in Fig. 4.

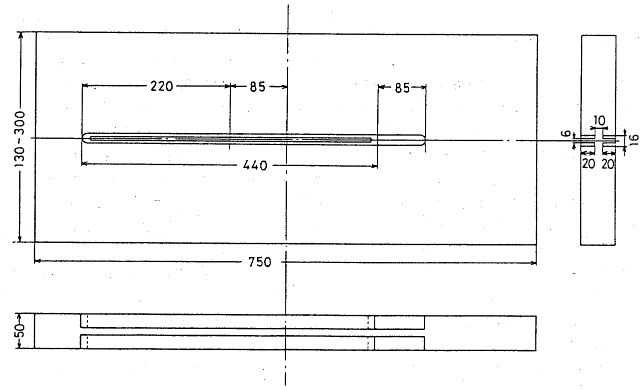

Fig. 4. 1/5 scale model of flat-topping cavity.

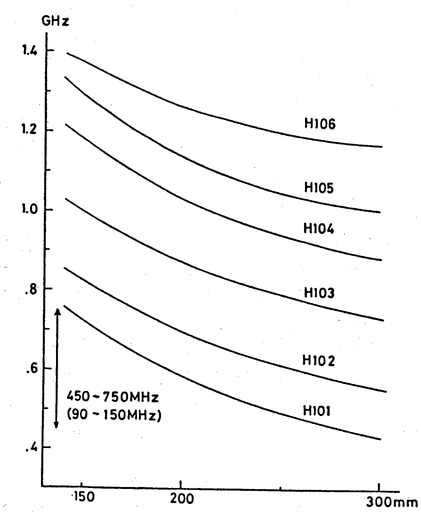

Fig. 5. Resonance frequencies of the model cavity.

Resonance frequencies of the cavity was measured up to 1.4 Ghz vs. position of the tuner plates. Fig. 5 shows the results. Various modes of resonances were observed. H_{101} mode resonance is used for flat-topping. The measured voltage distribution along the acceleration electrode shows a little frequency dependence.

VACUUM SYSTEM

The vacuum chamber of the six-separate sector cyclotron consists of 12 separate sections, these are 6 magnet chambers, 3 RF cavity chambers, a flat topping RF cavity chamber and 2 valley chambers. These chambers are sealed at their interfaces by pneumatic expansion seals which are requested to seal at different levels of magent and RF cavity chambers. The structure of the expansion seal is that two race-track shape doughnut flanges which compress the elastomer gaskets are linked with a pair of bellows welded inside and outside edges of the flanges to form a closed vessel. The vessel is inflated by compressed air and shrinked by evacuating it.[4]

The magnet chamber is demountable structure by a lift of the upper yoke. The trapezoidal stainless steel plates which are welded directly to the magnet poles tie up a side wall with elastmer gaskets. 36-pairs of trim coils are fixed to the pole faces. The trim coils are insulated by ceramic coating and/or by polymer sheets which are possibly the main source of the out-gas inside the cyclotron chamber.

The RF cavity and the flat topping cavity are single gap H_{101} mode resonators. These chambers are made of stainless steel.

The cavity chamber is to be withdrawn backwards from the stationary position for the maintenance of the cavity and also for the installation of the injection channels and of the beam diagnostic devices in the central region.

In the restricted space around the connecting sections between chambers where working conditions are terrible, a sealing method between the vacuum chambers by a pneumatic expansion seal is considered. The expansion seal is expected to absorb the reasonable dimensional tolelance and deformation of each chamber under evacuation process. This is also expected to simplify the easy connecting and disconnecting works of the chambers.

The main characteristics of the vaccum chamber is listed in Table 2.

The estimated out-gas load after 20 housr evacuation is around 2×10^{-2} Torr. ℓ/sec.

The cyclotron will be evacuated by cryopumps down to 2×10^{-7}Torr.

TABLE 2

Characteristics of the vacuum chamber

12 separate chambers
connected with pneumatic expansion seals

Diameter	inside outside	~ 3 m ~ 10 m
Height	Cavity section Valley section	~ 4 m ~ 0.5 m
Volume		60 m³
Surface Area inside vacuum	Metals: Fe, SUS, Al, Cu, etc. Insulation Sheet for Trim Coils Epoxy resin Polymer, Ceramic, Elastmer, etc.	~ 1,000 m² ~ 200 m² ~ 4 m² 3 m²
Feedthrough	Trim coil, cooling water, etc.	~ 1,500

INJECTION AND EXTRACTION SYSTEM

The accelerated beam from the AVF cyclotron will be transported by the beam line "A-course" through the "North Experimenal Room" of the present facility.[5] The beam will already be well shaped and momentum-selected at the exit of the "Room", and then will enter the injection line of the ring cyclotron after about 20 m drift space.

The beam optics from the AVF cyclotron to the entrance of this beam line will be so conveniently adjusted without any difficulty that many modes of operation, for example, high resolution/high quality mode, high intensity mode and very short pulse mode, etc., are easily available. Therefore the injection line operates as a matching section to the ring cyclotron. The elements are four bending magnets, eight quadrupole magnets two magnetic channels two electrostatic channels an additinal quadrupole, and two pairs of steering dipole magnets. The transversal emittances of the beam from the AVF cyclotron are supposed to be ~10π mm-mrad for the both planes, then the beam shapes in phase space will be ~3 mm×~3 mrad at the point A, which is an image point of the final doubly focussing and doubly achromatic point of the transport line from the AVF cyclotron. The beam envelope (half size) is almost less than 10 mm. The matching of the dispersion and the eigen ellipses in phase space is adjusted by the quadrupoles.

The extraction system consists of two electrostatic channels two magnetic channels, two bending magnets and several quadrupole magnets. The extracted beam is transferred to the beam transport lines for the experiments. The transversal emittance of the 400 MeV proton beam will be reduced to ~3π mm-mrad from ~10π mm-mrad by adiabatic damping. The optics study shows that the shape of phase space at the doubly focussing and doubly achromatic point are ~3 mm×~3 mrad and the beam envelopes (half size) are almsot less than 10 mm in the both planes for the emittance of ~10π mm-mrad.

CONTROL SYSTEM

The ring cyclotron will use the AVF cyclotron in operation as an injector. It is advantage to control both cyclotrons from the same operator console. However, the present operator console of the AVF cyclotron has been designed to control only AVF cyclotron and related beam transport lines. Because the computing power of this control computer is limited, it it not desirable to control both cyclotrons by this computer.

For the ring cyclotron, new computer control system is adopted, and the computer system of the AVF cyclotron will be used for data logging at the first stage of the operation of the cyclotron cascade.

The operator console of the ring cyclotron will be installed near the present operator console of the AVF cyclotron.[6]

The computers to control the ring cyclotron and beam transport system consist of a central computer and four sub-computers. The control functions of the accelerator are distributed to five computers and many intelligent device controllers. Each group control computer is connected to the system control computer through a computer network Ethernet. Each group control computer is also connected to many device controllers of accelerator devices through an optical fiber serial lines.

PRESENT STATUS

The cyclotron construction contract has already been made with manufacturer.

Open cut and readjustement of the land for the construction of the ring cyclotron vault has been started just in October of 1987. The design works for the cyclotron building and various utilities are now in progress.

The sector magnets of the ring cyclotron will be brought in the site from December of 1988. The scheduled date for delivery of the ring cyclotron including the distributed intelligent computer control system for the first beam acceleration test is spring of 1991.

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