SPIRAL SECTOR MAGNET OF THE PROPOSED
SIX SECTOR RING CYCLOTRON

K. Hosono, I. Miura, Y. Misaki, M. Kibayashi, T. Itahashi and A. Shimizu
Research Center for Nuclear Physics, Osaka University,
Mihogaoka 10-1, Ibaraki, Osaka 567, Japan

A ring cyclotron (Separated Sector Cyclotron) which can accelerate protons and light ions up to 400 MeV and 100 MeV/amu (K=400) has been proposed as a new facility at Research Center for Nuclear Physics (RCNP). The sector magnet of the ring cyclotron is described in this report.

Introduction

The main magnet system of the ring cyclotron consists of six spiral sector magnets. We have designed the spiral sector magnet under the following considerations. (1) The injection radius is 200 cm because we use the RCNP-AVF cyclotron as the injector where the extraction radius is 100 cm. In order to accelerate protons to 400 MeV, 65 MeV-proton beam from the AVF cyclotron is injected to the ring cyclotron. (2) In the acceleration, the vertical frequencies (ν_z) for the various ions and energies should be always larger than 1.0. (3) The maximum magnetic field of the sector is set to 17.5 kG and the magnet gap width is 60 mm in order to lighten the weight of the magnet.

Sector Magnet

The focusing properties and orbital stabilities of the various particles in the wide range of energies have been studied using the calculated field maps. Figure 1 shows a contour map of the calculated magnetic field of the sector magnet and the equilibrium orbits calculated using the field map. Calculated radial and vertical focusing frequencies and isochronous fields
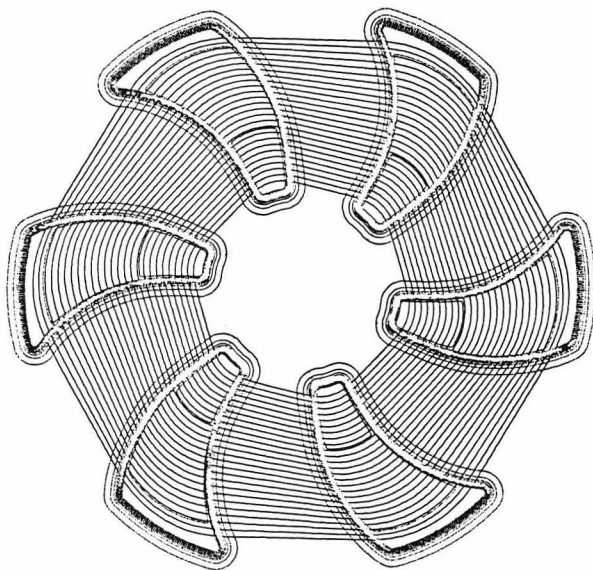
for maximum energies of various ions are shown in Fig. 2. The SSC has six spiral sector magnets. The sector angle is 21° to 26° and the maximum spiral angle is 14°. The weight of each sector magnet is about 350 tons and the yoke will be divided into several pieces by horizontal cuttings. The design characteristics of the sector magnet are listed in Table 1.

The schematic shape and geometrical size of the magnet are shown in Fig. 3. The radial pole edges are shaped stepwise into a Rogowski's curve as shown in Fig. 3. The magnet gap width is 60 mm. The ratio of the cross-sectional area of the yoke to that of the pole face is about 1.14. The pole-tips extend in the radial direction by five gaps toward the machine center from the first equilibrium orbit and by about four gaps
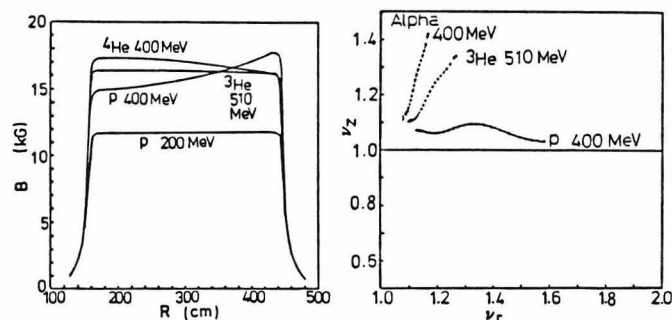
Fig. 2. Calculated radial and vertical focusing frequencies and isochronous fields for maximum energies of various ions.

Fig. 1. Contour map of the calculated magnetic field of the spiral sector magnet and the equilibrium orbits calcualted using the field map.

Table 1. Design characteristics of the sector magnet

Maximum energy		
	p	400 MeV
	d	200 MeV
	^{3}He	510 MeV
	^{4}He	400 MeV
	light-heavy ions	$400 \cdot Q^2/A$ MeV

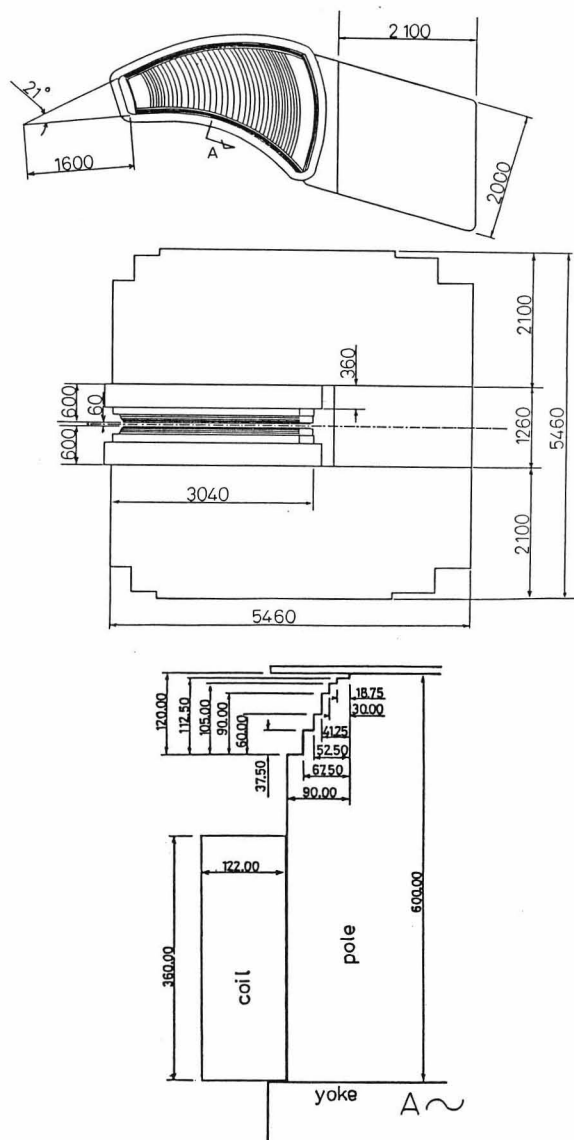| Magnet	
Number of sectors	6
Sector angle	21~26°
Maximum spiral angle	14°
Magnet gap	6 cm
Maximum field	17.5 kG
Iron weight	2100 tons
Main coil power	450 kW
Number of trimming coils	35
Injection radius	200 cm
Extraction raidus	400 cm

Fig. 3.   Shape and geometrical size of the sector magnet and shape of the radial pole edge.
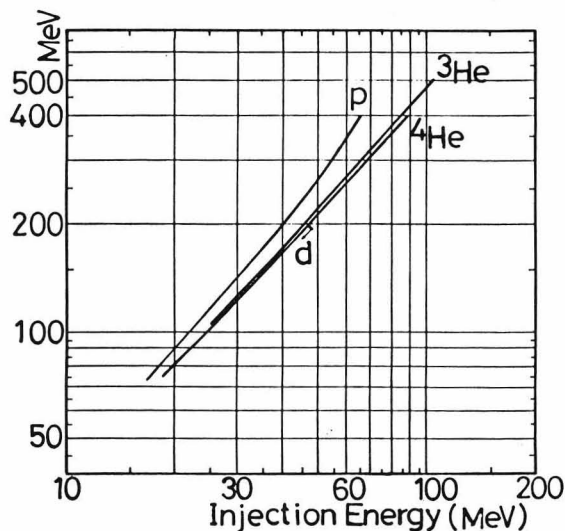

Fig. 4.   Relation between the injection energy and the particle energy accelerated by the SSC.

outward beyond the extracted orbit. The gap spacers and the elements for the injection and extraction will be inserted in these extended area. The maximum magnetomotive force is estimated to be 1.4×10^5 ampere-turns. The main coils are made with hollow copper conductors and will be formed in size of 122 mm in thickness and 350 mm in height. The coils are located outside of the vacuum chamber and will be excited with the maximum current of 1000 A. The maximum current density in the conductor is about 4 A/mm^2.

The relation between the injection energy and the particle energy accelerated by the SSC is shown in Fig. 4

Trimming Coils

The required radial field gradient for isochronism is produced by trimming coils of 35 pairs which will be mounted on the pole faces by special bolts. The bolts are made with soft magnetic iron welded to stainless steel, in order to reduce the magnetic perturbation due to bolt holes. In order to determine the radial widths and positions of the trimming coils, extensive calculations have been performed. As a example, the isochronous field for 400 MeV protons is modulated. The modulated field is $B = B_{iso} + A \cdot \sin(\frac{2\pi}{\lambda} r)$, where A is 3 Gauss and λ is 45 mm. Figure 5 shows the radial and vertical focusing frequencies calculated with the modulated field. The three kinds of 40, 60 and 80 mm are used as the radial widths of the trimming coils from various calculations. The shapes of the trimming coils
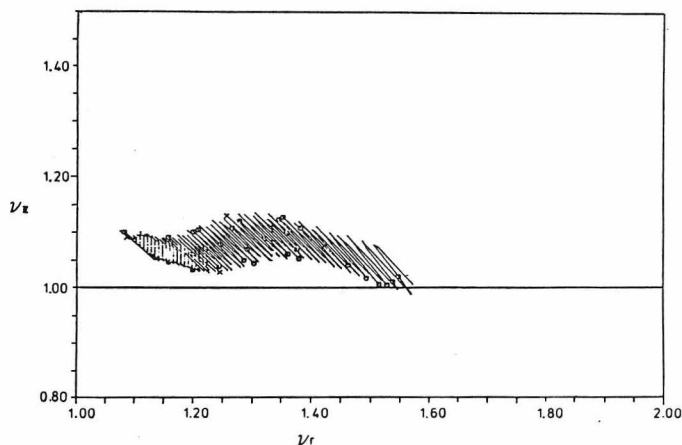

Fig. 5.   Radial and vertical focusing frequencies calculated with the modulated field described in the text.
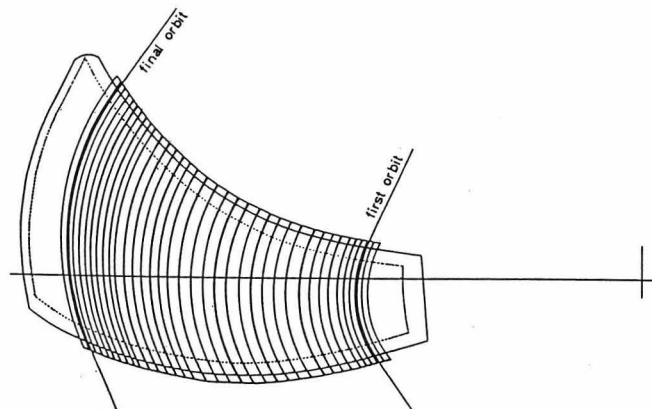

Fig. 6.   Arrangement of trimming coils.

are ones along the hard-edge equilibrium orbits (Gordon type). The schematic arrangement of the trimming coils are as shown in Fig. 6. The effective fields produced by the trimming coils have been calculated with the TRIM-code. Figure 7 shows the calculated effective fields when same current is applied individually at the base field of 16 kG. Figure 8 shows the comparison between the isochronous field for 400 MeV protons and a field distribution formed with 35 trimming coil pairs. In the calculation all trimming coils have been driven with same polarity. The difference between the ideal isochronous field and the field produced with 35 trimming coil pairs is oscillating and the maximum amplitude is less than 0.04%. Accelerated orbits have been calculated using the field distribution formed with 35 trimming coil pairs. The calculated phase-excursion in acceleration from injection radius to extraction radius is shown in Fig. 9.

Summary

The requirement for the sector magnet of the SSC is fulfilled sufficiently. Detailed designs of the magnet and trimming coils are in progress. The field strength and the field profile of the sector magnet depend on the iron material. Iron materials for the poles and the yokes are being made a search inquiry.
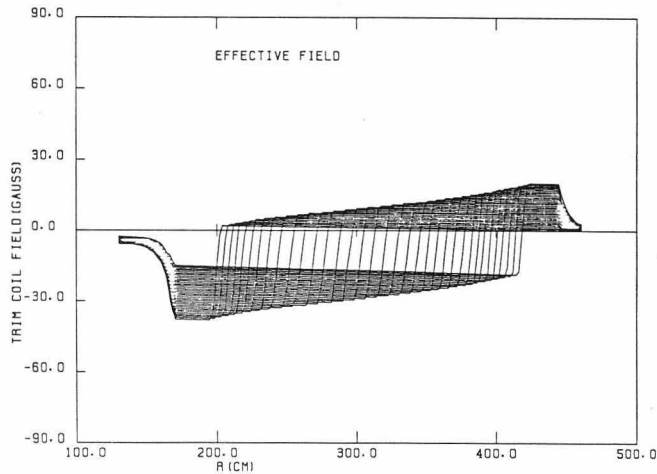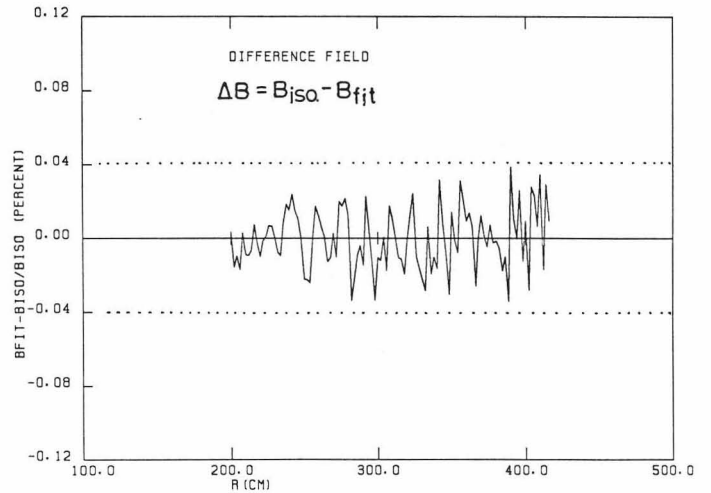
Fig. 8. Comparison between the isochronous field for 400 MeV protons and a field formed with 35 trimming coil pairs.

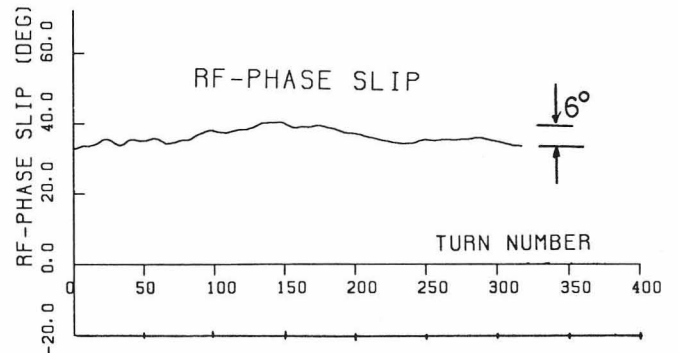Fig. 7. Effective fields of the trimming coils calculated with the TRIM-code.

Fig. 9. Phase excursion from the injection radius to the extraction radius calculated using the field formed with 35 trimming pairs.