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MAGNET MODEL STUDIES FOR A PROPOSED RING CYCLOTRON SYSTEM AT RCNP

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Abstract. – An intermediate energy particle accelerator complex is being designed as a new accelerator facility of RCNP. The proposed facility consists of two separated sector cyclotrons (ring 1 and ring 2) and an injector cyclotron. A 1/3.5-model magnet with trim coils for the ring 1 and a 1/4-scale model magnet for the ring 2 were made to study various magnetic field properties. The magnetic field characteristics of these model are presented in detail. Isochronous fields produced by trim coils are also discussed.

1. Introduction.– An intermediate energy particle accelerator complex with a maximum proton energy of 550 MeV has been proposed[1)] as a new accelerator facility of RCNP. The proposed facility[1)] consists of two separated sector cyclotrons (ring 1 and ring 2) and an injector cyclotron. The design considerations of the magnets of the ring 1 and the ring 2 can be summarized as follows:
(i) the Ring 1 (N=4, R_{inj}=135cm, R_{ext}=340cm, K=230) will provide energies up to 190 MeV and 56 MeV/amu for protons and light ions, respectively.
(ii) The Ring 2 (N=8, R_{inj}=340cm, R_{ext}=470cm, K=460) will provide energies up to 550 MeV and 118 MeV/amu for protons and light ions, respectively.

Both the ring magnets have 8cm gap. The ring 1 has four 33° radial sectors. The ring 2 has eight spiral sectors. A 1/3.5-scale model magnet with trim coils for the 1st ring and a 1/4-scale model magnet for the 2nd ring have been made to study various magnetic field properties. Magnetic field measurements have been made using a single Hall probe that was positioned by a high precision numerically controlled apparatus. The magnetic field characteristics of these model and the results of orbital analyses are described in this report. Isochronous fields produced by trim coils are also described.

2. Model Measurements and Orbital Analyses for the 1st Ring.– A 1/3.5-scale model magnet, weighing about 8 tons, is shown in fig. 1. The radial pole edges are shaped stepwise into a Rogowski's curve. The gap width is 22.9 mm and the sector angle is 33°. The magnet can be excited with max. 4.5×10^4 AT by a pair of pole coils (2 × 87T).

Magnetic field mapping was made on a cartesian grid. The apparatus is shown in fig. 1. The probe carriage on cross sliders was driven with ball-screwed spindles (5 mm pitch) directly coupled to stepping motors (200 pulse/rev.). The position of the carriage was monitored with shaft encoders (200 pulse/rev.) coupled also directly to the stepping motors. A BHT-910 Hall generator was used for the magnetic field measurements. The Hall probe was mounted on an end of aluminum arm stretched from a probe carriage to the center line of the model magnet. The magnetic field mapping, the data acquisition, reduction and storage were automatically controlled by a PDP-11/10 computer and CAMAC system.

The center of the active area of the Hall probe on the mapping system was determined by making a series of scans over a field bump generated by a iron needle with a coil. The iron needle with a coil was mounted on the magnet pole tip at precisely known location relative to the machine center. The

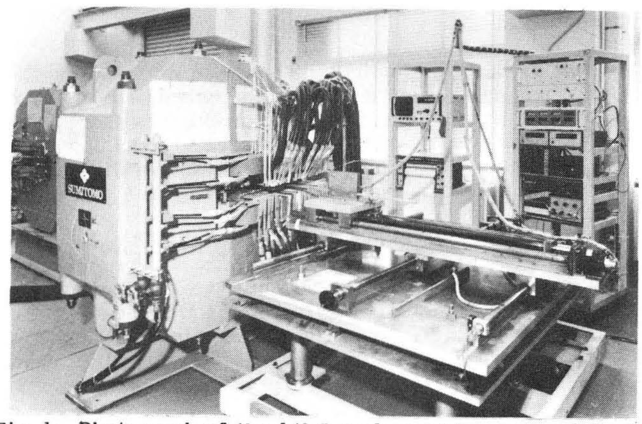

Fig. 1: Photograph of the 1/3.5-scale model magnet of the 1st ring cyclotron and the magnetic field mapping apparatus.

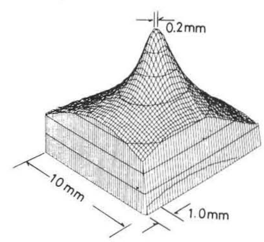

Fig. 2: Field bump made by an iron needle with a coil. The absolute position of a Hall probe was determined using the field bump.

results of the measurement are shown in fig. 2. We concluded that the center of the active area of the Hall probe on the mapping system could be determined within an accuracy of 0.2 mm. The Hall probe was calibrated by comparison with the output of a Spectro-Magnetics 5300 NMR probe positioned adjacent to the Hall probe in a uniform field.

The magnetic field profiles of our model magnet were mapped at excitation levels of 4 kG (coil current I=30A), 5 kG (50A), 7.5 kG (75A), 10 kG (100A), 12 kG (125A), 14 kG (150A), 16 kG (175A), 17 kG (200A) and 17.5 kG (220A). From the measured field data of one sector magnet, We corrected the values of the field in the valley region using the simple super-

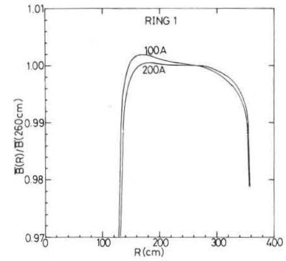

Fig. 3: Relative strength of average magnetic fields as a function of full-scale radius.

position formula of B(R, θ) = B(R, θ) + B(R, 90°-θ) on considering effects of a neighbouring magnet. The field data were smoothed by the method of fourier-analysis and Lanczos' weighed re-synthesis[2]. Figure 3 shows relative strength of average magnetic fields as a function of full-scale radius for the 10 kG (I=100A) and the 17 kG (I=200A) fields. There is at most 0.3% difference in field shape between the two in the range between the injection (135 cm) and the extraction (340 cm) radii. Little absence of saturation effects at 16∿17 kG leads to nearly the same dynamics of particle orbits at low and high field levels.

Orbit property of the 1st ring has been studied using the measured field data. Figure 4 shows the calculated isochronous field for maximum energy of various ions as a function of full-scale radius and the calculated radial and axial focussing frequencies of the ions of maximum energies. We will be free of instabilities caused by the essential resonances.

3. Measurements of Trim Coil Fields for the Ring 1. The required radial field gradient for isochronism was produced by trimming coils which are mounted onto the pole faces. We made 25 circular trimming coil pairs for a 1/3.5-scale model magnet of the ring 1. The plan view is indicated in fig. 5. The trim coil pairs were made by Cu-sheets of 2 mm in thickness. The sheets were stuck on epoxy resins plates of 2 mm in thickness. The radial width of each coil is either 20 mm or 30 mm.

The effective fields of each trimming coil at several base fields were measured. Figure 6 shows the effective fields of each coil at a base field of 14.8 kG. The trimming coil currents to provide the isochronous fields of 193 MeV protons as shown in fig. 4 were calculated using the effective fields at a base field. All trimming coil pairs were drived with same polarity using 5 power supplies and the predicted field was measured. However there was a problem in matching the desired field by using the effective field data of trimming coils at a base field which has no radial field gradient. Thus the base field was replaced with approximate isochronous field measured above and we again measured the effective fields of trimming coils. Figure 7 shows these effective fields of trimming coils. In order to provide the more precise isochronous field of 193 MeV protons, the trimming coil currents were recalculated using effective fields as shown in fig. 7. The results of the calculation and a schematic representation of trimming coil currents drived by 5 power supplies are shown in fig. 8. Figure 7 shows a comparison of the measured field with the ideal isochronous field for 193 MeV protons. In this case, the measured field are well fitted to the ideal field. In the same method, we tried to provide the isochronous field of 223 MeV α-particles. The results are shown in fig. 9. Figure 9 also shows the focussing frequencies of 193 MeV protons and 223 MeV α-particles which are calculated using the measured isochronous fields. In this figure, solid lines are the results calculated using the measured isochronous field and dashed lines are the results from ideal isochronous fields as shown in fig. 4. The range of ν_r and ν_z values is satisfactory for the operation of a four

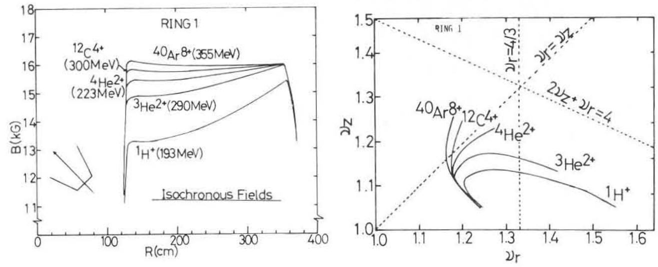

Fig. 4: Calculated isochronous fields in the middle of sector and the radial and axial focussing frequencies for maximum energies of various ions. These results were obtained using measured magnetic field data.

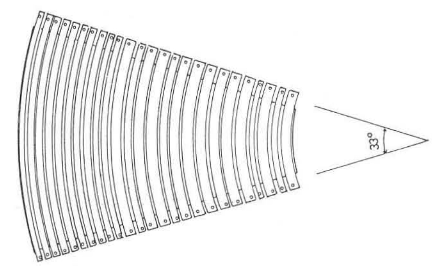

Fig. 5: Plan view of a model of trimming coils for the ring 1.

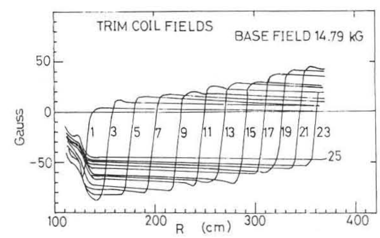

Fig. 6: Effective fields of trimming coils (I_T = 100 A) at the base field of 14.8 kG.

sector ring cyclotron, though there is a little difference in the injection and extraction regions. The difference mainly occurs from the reasons that trimming coils were drived with same polarity and with only 5 power supplies. As a further aid to design we are planning to use more exact model of trimming coils.

4. Model Measurements and Orbital Analyses for the 2nd Ring.- A 1/4-scale model magnet for the 2nd ring was also prepared to study magnetic field properties. The model magnet, weighing about 5 tons is shown in fig. 10. The radial pole edges are also shaped stepwise into Rogowski's curve. The gap width is 20 mm. The magnet can be excited with max. 4.5×10^4 AT by a pair of pole coils (2 × 79T). The measuring system of the magnetic fields are same as that for the 1st ring.

The magnetic field profiles of the model magnet were mapped at excitation levels of 5 kG (coil current I=50A), 7.5 kG (75A), 10 kG (100A), 12.5 kG (125A), 15 kG (150A), 15.8 kG (160A), 17 kG (175A) and 18 kG (190A). From the measured field data of one spiral sector magnet, we also corrected the values of the field in the valley region using the formula of B(R, θ)=B(R, θ) + B(R, θ -45°). Figure 11 shows average magnetic fields as a function of full-scale radius. There is about 0.42% difference in the field shape of relative strength between 50A and 190A fields. This shows no significant saturation effect.

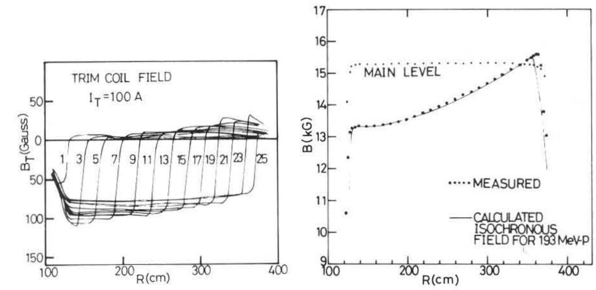

Fig. 7: Effective fields of trimming coils at the field with radial field gradient and a comparison of the measured field with ideal isochronous field for 193 MeV protons. These data are plotted radially in the middle of sector.

TRIM COIL CURRENTS

COIL	AMPS
1	-0.001
2	-21.706
3	-0.003
4	-0.001
5	-46.900
6	-45.393
7	-98.107
8	-71.802
9	-108.626
10	-87.762
11	-95.521
12	-80.725
13	-149.699
14	-85.232
15	-186.920
16	-128.160
17	-92.402
18	-149.674
19	-104.212
20	-114.884
21	-144.027
22	-117.025
23	-143.612
24	-199.864
25	0.007

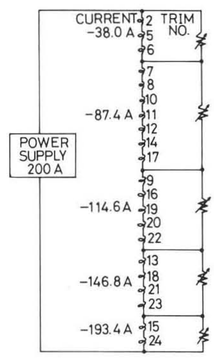

Fig. 8: Calculated trimming coil currents using the effective fields at the field with radial gradient and schematic representation of the trimming coil currents drived by 5 power supplies.

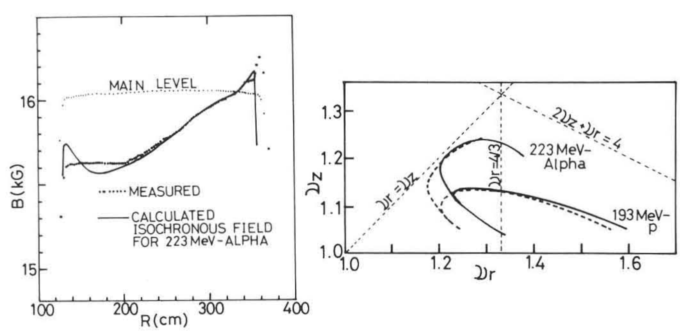

Fig. 9: A comparison of the measured field with ideal isochronous field for 223 MeV α-particles and focussing frequencies of 193 MeV protons and 223 MeV α-particles which are calculated using the measured isochronous fields. Solid lines are the results calculated using the measured fields and dashed lines are the results from ideal isochronous field.

The orbital calculations were made using the magnetic field data. Figure 12 shows the calculated average isochronous fields of various ions as a function of full scale radius and also shows the calculated radial and axial focussing frequencies of various ions. A little correction of the sector angle of the 2nd ring is necessary in order to obtain higher energies than about 510 MeV. The required radial field gradient for isochronism shown in fig. 12 will be produced by trim coils. The trim coils for a 1/4-scale model magnet are being made.

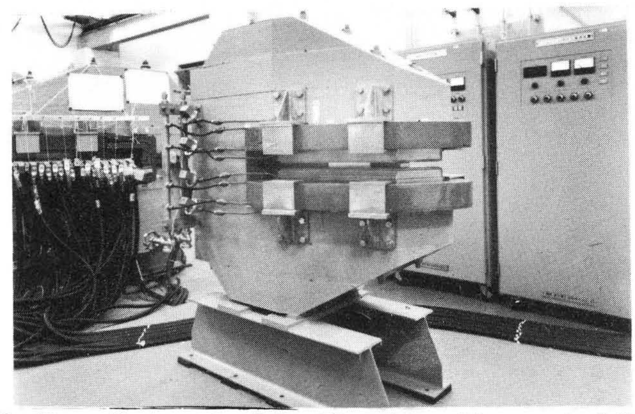

Fig. 10: Photograph of the 1/4-scale model magnet of the 2nd ring.

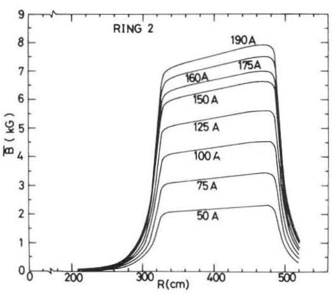

Fig. 11: Average magnetic fields as a function of full-scale radius.

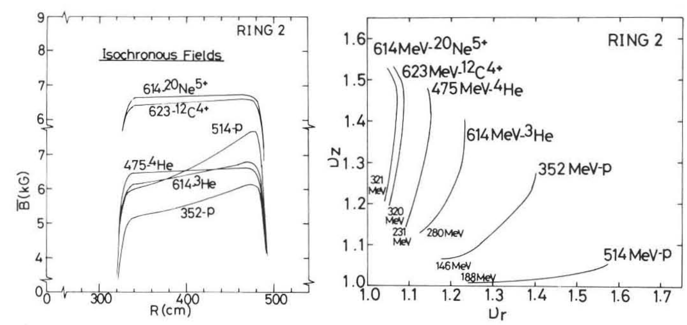

Fig. 12: Calculated average isochronous fields and radial and axial focussing frequencies using measured magnetic fields for various ions.

5. Summary.- A 1/3.5-scale model magnet of the 1st ring and a 1/4-scale model magnet of the 2nd ring were made to study magnetic field properties. From the results of the measured fields and the calculations, we concluded that the requirements for the 1st ring of the proposed separated sector cyclotrons were fulfilled sufficiently. On the other hand, a little correction of the sector angle of the 2nd ring is necessary because the model magnet can not be provide higher energies of protons than about 510 MeV. We are modifing the model magnet of the 2nd ring.

References:

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