SECTOR MAGNET OF THE RCNP RING CYCLOTRON AND THE ISOCHRONIZATION

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ABSTRACT

The RCNP six-sector ring cyclotron is in operation for nuclear physics experiments. We briefly recall the sector magnet of the ring cyclotron. Then we present the method of the magnetic field setting for isochronization and the results.

1. SECTOR MAGNET

A schematic mid plane view of the sector magnets of the ring cyclotron including injection and extraction devices is shown in Fig. 1. The parameters of the sector magnet are listed in Table 1. Figure 2 shows a photograph of the sector magnets installed in the cyclotron vault. A vacuum chamber made by SUS is welded at the side faces of the pole. Figure 3 shows the schematic cross sectional view of the pole edge section.

The maximum magneto-motive force was estimated to be about 1.4×10^5 ampere-turns to obtain the maximum field strength of 17.5 kG. The main coil and the auxiliary coil consist of 80 turns and 20 turns of copper hollow conductors, respectively. We can control the magnetic field strength of 500 Gauss for each sector by the auxiliary coil. The 36 pairs of trim coils are fixed on each pole face of the sector magnet. Two pairs among them are used as harmonic coils. Each trim coil is coated with alumina-ceramics ($A\ell_2O_3$) for insulation and is fixed on the pole face by SUS-Fe welded volts to reduce the magnetic perturbation due to bolt holes.

High current stability is required for the power supplies of main, auxiliary and trim coils to obtain a high quality beam. In order to acieve high stability, a precision shunt resistance made of germanium-manganese-copper alloy (ZERAMIN) is used as a current sense. The temperature coeffi-

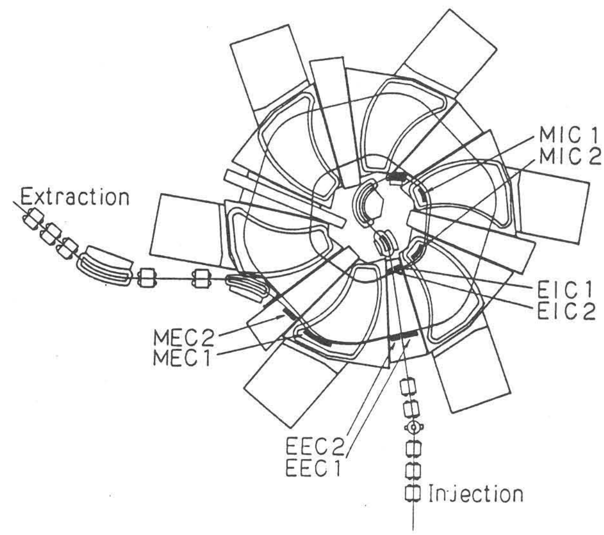

Fig. 1. Schematic mid plane view of the magnet system of the ring cyclotron.

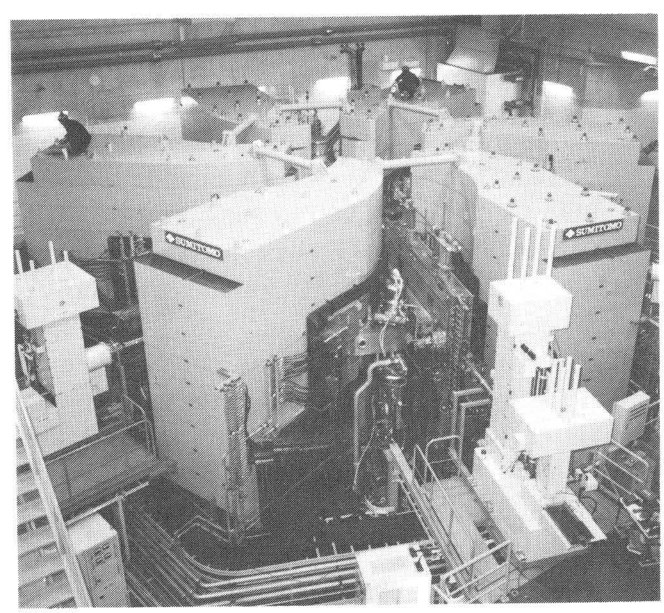

Fig. 2. Photograph of sector magnets installed in the cyclotron vault.

cient of the shunt resistance is less than 3 ppm/°C. The shunt resistance of the main and auxiliary coils are cooled by temperature controlled water kept at 27.0 ± 0.1°C. In this condition, the current stability of $\pm 2 \times 10^{-6}$ is obtained at main coil currents of 650A and 400A.

2. FIELD MAPPING

We used the non magnetic pneumatically driven system for field mappings. Twenty Hall generators were fixed along a radial arm. With the mapping apparatus, we can measure field maps with radial interval of 10 mm or 20 mm step between 1600 mm and 4300 mm and with azimuthal interval of 0.4° step over the whole region of 360°. A computer (μ-VAXII) is used for arm driving system, data acquisition system and control system of power supplies. The details of the measuring system have been described elsewhere.[1)]

3. MAIN RESULTS OF THE FIELD MAPPINGS

Various modes of the field setting procedure have been examined to reproduce field strength and distribution as quickly as possible. In a cycling procedure, it takes about 1.5 hour for higher field strength than 13 kG and 2-4 hours for low one. Excitation characteristic of a sector magnet is shown in Fig. 4.

Measurement of the base field distributions of six sectors was carried out for seven main coil current of 250A, 350A, 400A, 450A, 500A, 550A and 650A. The main coil currents correspond to the field strength of 8.5 kG, 11.7 kG, 13.2 kG, 14.5 kG, 15.6 kG, 16.3 kG and 17.5 kG, respectively. The injection and extraction elements were excited during the measurement.

The base field distributions along the center line of the No.5-sector magnet for the seven levels of main coil current and the relative strength are shown in Fig. 5. There is at most 0.2% difference in the field shape among the seven levels. In order to obtain the required isochronous field distribution along the sector-center line, we have adopted a method similar to that used at GANIL.[2)] Equilibrium orbits are calculated using the measured base field distributions and the ratios between the field

Table 1
Parameters of the spiral sector magnet.

Number of sector magnets	6
Sector angle	22° ~27.5°
Gap width	60 mm
Height of magnet	5.26 m
Overall diameter	14.4 m
Total weight	~2200 tons
Injection radius	2 m
Extraction radius	4 m
Maximum magnetic field	17.5 kG
Maximum ampere turns	1.4×10^5 A.T
Maximum current	900 A
Maximum power	440 kW
Number of trim coils	36 pairs×6
Maximum current	500 A
Total trim coil power	~350 kW

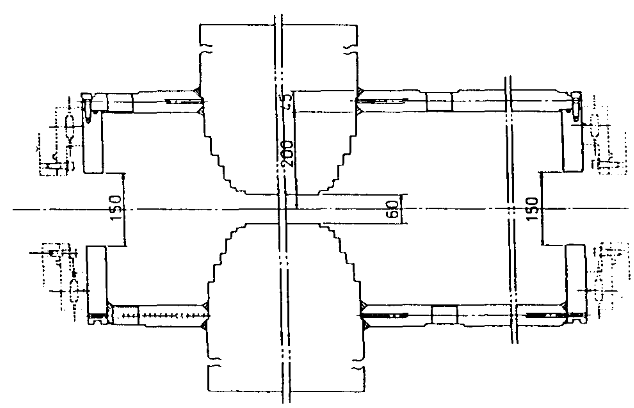

Fig. 3. Schematic cross sectional view of the pole edge section.

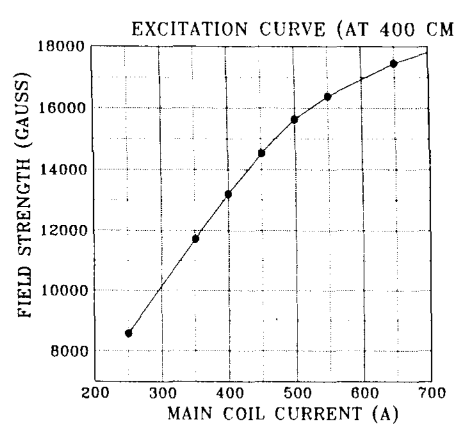

Fig. 4. Excitation characteristic of a sector magnet.

strength and the radius averaged along the closed orbit ($\bar{B}$ and $\bar{R}$) and those at the sector-center line (B_c and R_c) $K_b = B_c/\bar{B}$ and $K_r = R_c/\bar{R}$ are calculated. The K_b and K_r values of No.5-sector at the seven levels of main coil currents are shown in Fig. 6 and those of the six sectors at 500A (14.5 kG) excitation are shown in Fig. 7. Perturbation due to the injection and extraction elements was observed, more or less, in all sector magnets.

4. TRIM COIL FIELD

Measurement of the trim coil fields was performed for the No.5-sector magnet only at the base fields of the main coil current of 250A, 450A, 550A and 650A. In order to obtain the non-linear effectiveness of the trim coil field, four kinds of the measurement were carried out for each base level of the main coil current. The field gradient of the isochronous radial field distribution is positive for protons of higher energy than 200 MeV and is negative for all energies of heavier ions than protons. In the measurement, the current was fed to each trim coil to make the radial field gradient corresponding to the gradient of the isochronous field distributions of 300 MeV and 400 MeV protons (positive gradient) and 400 MeV and 100 MeV alpha particles (negative gradient). Figure 8 shows examples of the trim coil field distributions along the sector center line in the case of the field gradients corresponding to 400 MeV proton and to 400 MeV alpha particle field gradients at the 450A base field, respectively. In order to estimate the difference of the effectiveness of the trim coil fields among the six sectors, the field maps with the field gradients were also measured for each sector.

5. ISOCHRONIZATION

An isochronous field distribution along the center line of each sector magnet can be calculated by using the measured data of $B_c(N,I,r)$, $K_r(N,I,G,r)$ and $K_b(N,I,G,r)$, and the optimum currents of the main and trim coils to reproduce isochronous field distribution can be obtained by using the data of B_c, $B_T(I,G,r)$ and $\Delta B_T(N,I,G,r)$, where B_c, K_r, K_b, B_T and ΔB_T are main level field along the sector center-line, $K_r = r_c/\bar{r}$, $K_b = B_c/\bar{B}$, trim coil effective field of the No.5-sector magnet and the

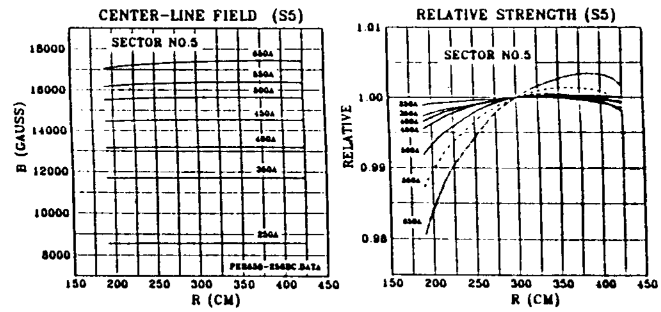

Fig. 5. Base field distributions along the center line of the No.5-sector and the relative strength.

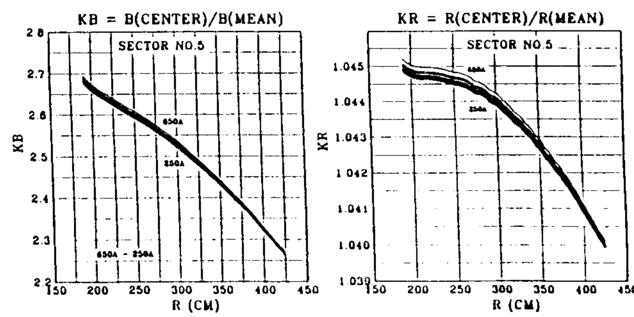

Fig. 6. K_b and K_r values of the No.5-sector at the seven main coil levels.

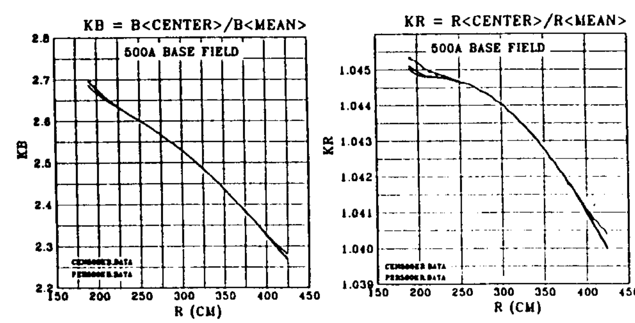

Fig. 7. Comparison of K_b and K_r values among the six sectors at 500A excitation.

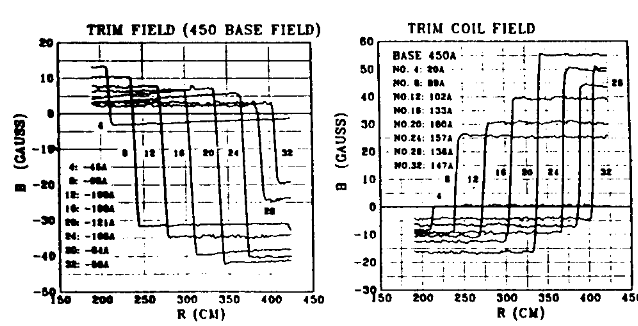

Fig. 8. Examples of the trim coil field distributions along the sector center line at the field gradients corresponding to the 400 MeV protons 400 MeV alpha particles at 450A base field.

difference of the all time coil effectiveness among the six sectors, respectively. These are dependent on sector (N) main coil current (I), gradient of the isochronous field (G) and radius of the sector center-line (r).

When a particle and the acceleration energy are given, our code calculates the isochronous field and determines first the required main field level on the sector center-line and then interpolates the B_c, K_r, K_b between the measured main levels to give $B_c^0(N,r)$, $K_r^0(N,r)$ and $K_b^0(N,r)$ at the required level and field gradient. The required field distribution for acceleration of each sector can be calculated using the B_c^0, K_r^0 and K_b^0 values. Next, the main and trim coil currents are calculated in order to reproduce the isochronous field. We have no data of trim coils fields for the other sector magnets except No.5-sector. Therefore the required field distributions for the sector magnets except No.5-sector can be obtained by taking account of the ΔB_T^0 at the required level and field gradient which are given by interpolation of ΔB_T measured at various levels and gradients. The optimum coil currents are automatically searched with a computer code.

6. ACCELERATION

After cycling of the magnets, the calculated coil currents are fed to the coils. We have accelerated protons to 300 MeV (E_{inj}=52.7 MeV).

Figure 9 shows measured beam currents on a 1 mm wire of the main probe from the injection radius to the extraction radius. Figure 10 shows the particle phase excursion from the injection to the extraction by a dotted line in the case of setting the calculated coil currents and by a solid line in the case of a slight correction of the trim coil currents.

7. CONCLUSION

Magnetic field distributions of the sector magnet of the RCNP ring cyclotron were measured. The values of B_c, K_r, K_b, B_T and ΔB_T were obtained at various combinations of the main levels, field gradients, trim coil, currents, etc. These data bases are used to reproduce isochronous fields of various ions and energies. We have accelerated protons to 300 MeV by setting the calculated coil currents. We have no serious problems which occur on setting the calculated coil currents, through the phase excursion appears in acceleration. The phase excursion can be corrected by a slight adjustment of trim coil currents.

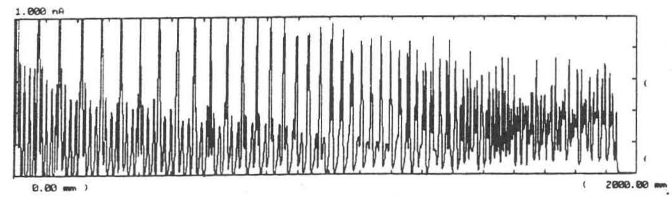

Fig. 9. Beam current measured by a wire probe from injection radius to extraction radius.

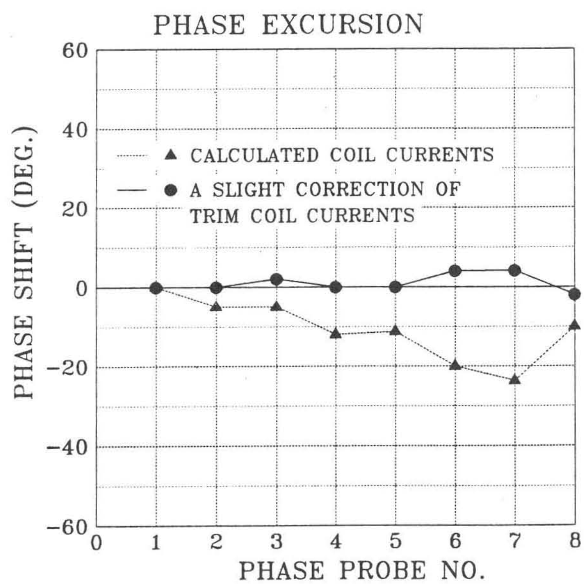

Fig. 10. Phase excursion.

REFERENCES

1) K. Hosono et al., RCNP-Annual Report 1989, p.179.
2) M. Barre et al., Proc. of the 9th Int. Conf. on Cyclotron and Their Applications, Caen (1981), p.371.