Orbit Analysis for the RIKEN Superconducting Ring Cyclotron

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Abstract

An "RI beam factory" has started to be constructed as the next project of the RIKEN Accelerator Research Facility (RARF)[1]. The "RI beam factory" aims at production and acceleration of radioactive isotope beams covering the whole mass region. It requires the energy of ion beam to be higher than 100 MeV/nucleon. To accomplish this requirement, the following two ring cyclotrons have been adopted as post-accelerators of the existing RIKEN Ring Cyclotron (RRC): a 4-sector ring cyclotron for the first stage (IRC) and a 6-sector superconducting ring cyclotron for the second stage (SRC)[2]. The sector magnet of the SRC has to be flexible enough to generate isochronous fields in a wide range of energies and for various q/A values. In this report we describe the isochronous field generation and orbit analysis of the SRC.

1 Introduction

The maximum acceleration energy of the SRC was determined by experimental requirements. The SRC is expected to boost the energy of ion beam up to 400 MeV/nucleon for light heavy ions like carbon and 150 MeV/nucleon for very heavy ions like uranium. Beam current is expected to be more than 100 pμA for light heavy ions and about 0.2 pμA for 150 MeV/nucleon uranium ions. Figure 1 shows the region of expected ions from the SRC (grey area) and typical ions (white circle).

Main parameters of the SRC are listed in Table 1. Velocity gain factor is 1.51. Figure 2 shows a layout of the SRC. Six sector magnets, three main resonators, one flattop resonator and injection and extraction devices together with injection and extraction orbits are displayed.

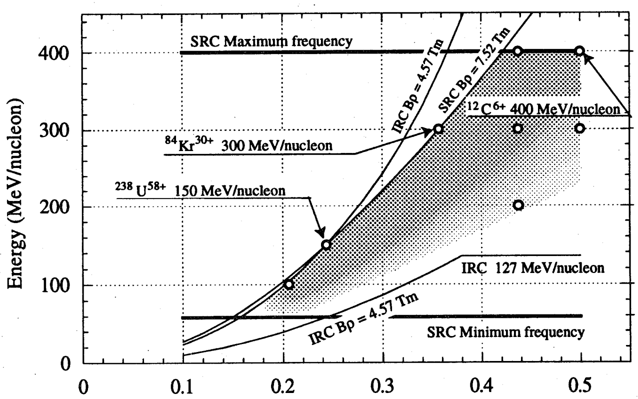

Fig. 1 Performance expected for the SRC.

Table 1
Main parameters of the SRC

Number of sectors		6
Harmonics		6
Mean radius	injection	3.56 m
	extraction	5.36 m
Orbit frequency		3.00 - 6.35 MHz

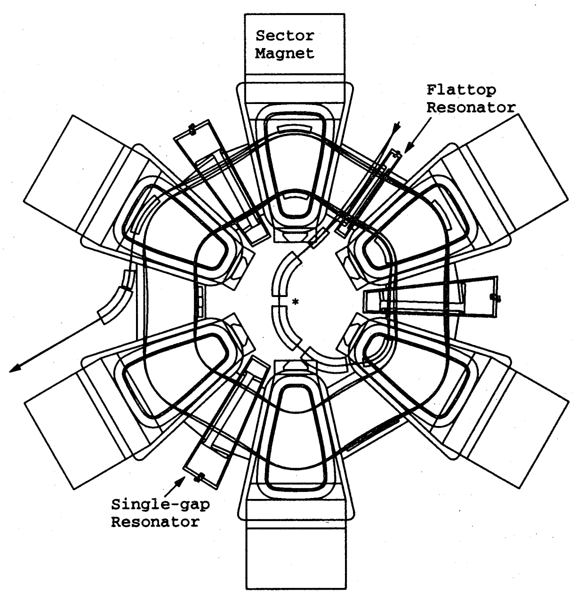

Fig. 2 Layout of the SRC.

2 Isochronous field generation

The maximum magnetic field is required for the acceleration of 150 MeV/nucleon $^{238}U^{58+}$. The magnetic field of the sector magnet is 4.0 T at the injection and 4.3 T at the extraction. In the case of 400 MeV/nucleon $^{16}O^{7+}$, the magnetic field is 3.3 T at the injection, and 4.1 T at extraction side.

In order to realize the high magnetic field and various magnetic inclinations, the sector magnet of the SRC has a set of superconducting main coils for base field generation, five sets of superconducting trim coils for coarse fitting to the isochronous field and about 20 sets of normal conducting trim coils for fine adjustment to the isochronous field. Magnetic field distribution is calculated by three dimensional code TOSCA[3].

2.1 Pole and superconducting main coil

Size of the superconducting main coil is 284 mm (width) x 310 mm (height). The maximum excitation current is 6 MA for one sector magnet (two coils). The superconducting main coil is installed inside a He vessel made of stainless steel which is tightly fixed to the cold pole. Pole gap is 380 mm[4].

Sector angle of the pole is 25 degree at injection side. From the middle of the radial direction, the pole shape has a curvature in order to increase the axial betatron frequency ν_Z at the extraction side.

Construction of a 1/1scale model of the pole and the main coil is started[5].

2.2 Yoke

Stray field in the valley region is used in order to increase axial focusing force. Distribution of the stray field is affected by the shape of the yoke. Thus by modification of the shape of the yoke, axial betatron frequencies can be controlled. Figure 3 shows original yoke shape (upper) and modified one (lower). The axial betatron frequency has the maximum value in the case of acceleration for 150 MeV /nucleon $^{238}U^{58+}$, which is around the resonance line of ν_Z = 1.5. By this modification, the maximum axial betatron frequency decrease by 0.05 (Fig.4) without decrease of the minimum axial betatron frequency in the case for 400 MeV/nucleon $^{12}C^{6+}$, which is near the resonance line of ν_Z=1. Optimization of the yoke shape is under way, taking mechanical design into consideration.

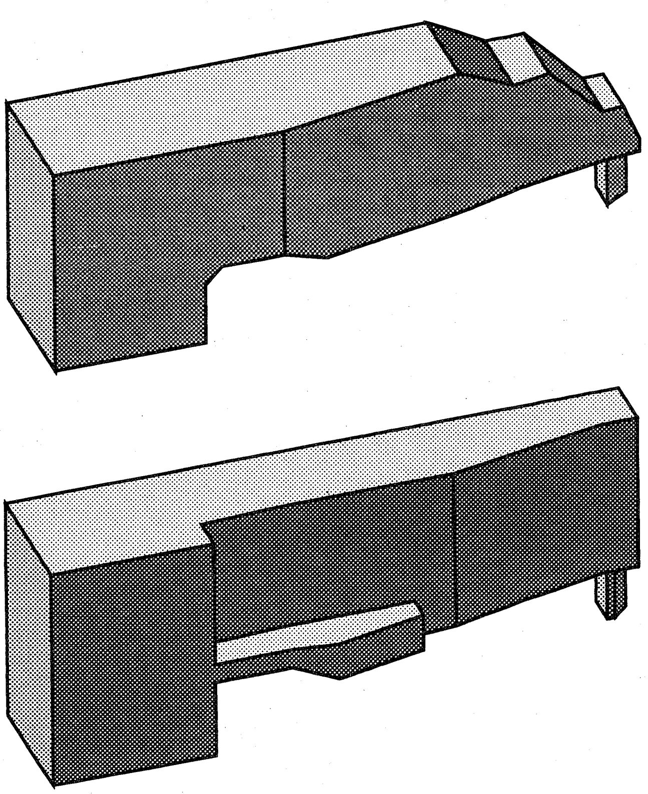

Fig. 3 Two yoke shapes of a quarter part is displayed: original (upper) and modified (lower).

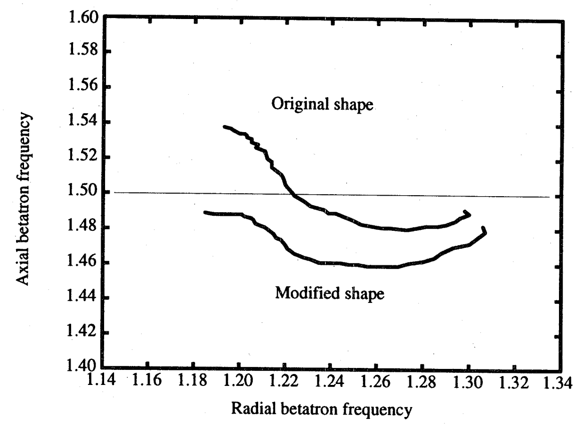

Fig. 4 Working paths of radial and axial betatron frequencies for two different yoke shapes for 150 MeV/nucleon $^{238}U^{58+}$ ions.

2.3 Superconducting trim coil

Five sets of superconducting trim coils are placed on the inner surface of the cold pole. Two sets at the extraction side have current returns at the extraction side, which are not wound along beam orbits but just straight in the beam region in order to avoid concave curvature of conductors. The other three sets have current returns at the injection side. Schematic view of the superconducting trim coils is shown in Fig. 5. The first coil on the injection orbit is wound along beam orbit, then it gradually becomes straight towards the extraction side.

Using the five sets of superconducting trim coils, it is possible to adjust various distributions of isochronous fields within ±0.1 %.

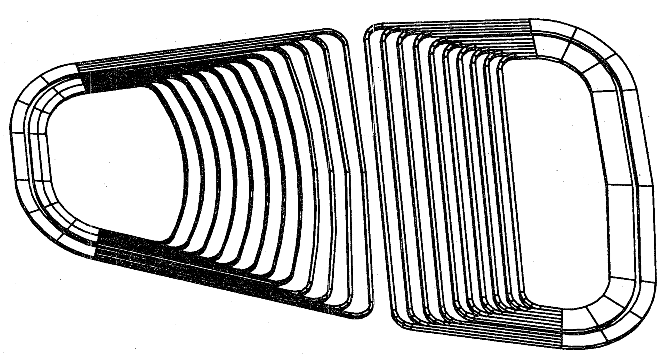

Fig. 5 Configuration of the superconducting trim coils. Two of five sets have current returns at the extraction side and the others have current returns at the injection side.

2.4 Normal conducting trim coil

Normal conducting trim coils are used for fine adjustment to the isochronous field. We plan to use about 20 coils at acceleration region and one or two more coils at injection and extraction regions.

The maximum current of each coil is considered to be 500 A. By using the normal conducting trim coils, errors from isochronous condition becomes less than ±0.01 %. Schematic layout of the normal trim coils with the pole is shown in Fig. 7. The conductor is shaped along the beam orbit. Cross-sectional view around the symmetry plane of the magnet is shown Fig. 8. The wall of beam chamber is used in common as the wall of the cryostat. The normal conducting trim coils are put in the wall.

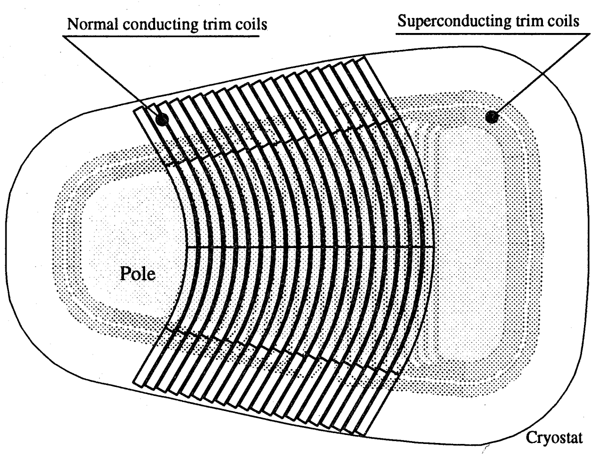

Fig. 6 Schematic layout of normal conducting trim coils. Current returns of the coils are not shown in this figure, but will be put at the extraction side.

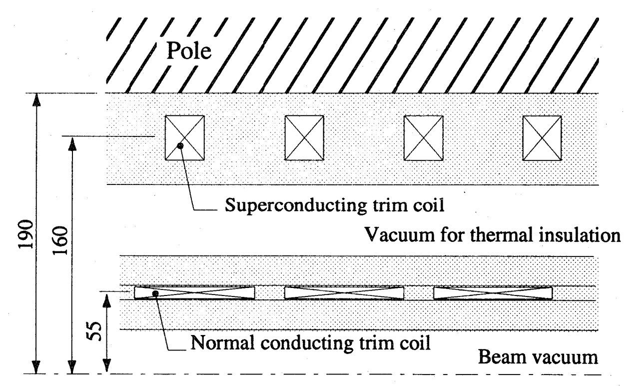

Fig. 7 Cross-sectional view around the symmetry plane of the pole. The vertical position of the superconducting trim coils is 160 mm from the center and that of normal trim coils is 55 mm.

3 Orbit analysis

Working paths of radial and axial betatron frequencies for the SRC are spread in a wide region of the ν_r - ν_z diagram. Figure 8 shows the working paths of typical ions. All the working paths are between the resonance lines of ν_z=1 and ν_z=1.5. But some of them are close to the resonances. In the case that the extraction energy higher than 300 MeV/nucleon, the working path crosses ν_r=1.5 line. Detail study is in progress.

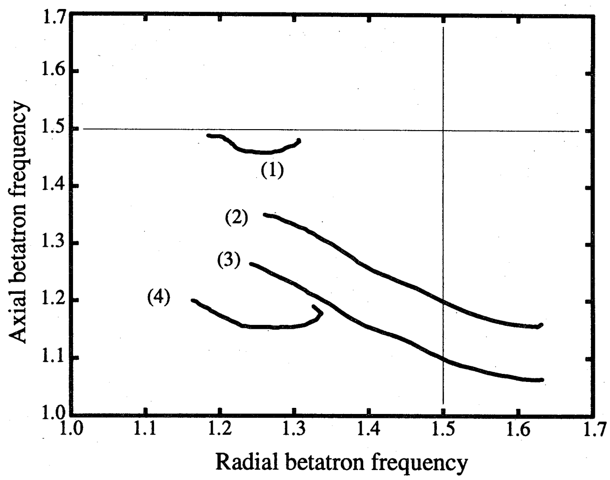

Fig. 8 Working paths of the radial and axial betatron frequencies of typical ions for the SRC:
(1) 150 MeV/nucleon $^{238}U^{58+}$,
(2) 400 MeV /nucleon $^{16}O^{7+}$,
(3) 400 MeV/nucleon $^{12}C^{6+}$ and
(4) 200 MeV/nucleon $^{16}O^{7+}$.

4 Summary

Design study of the sector magnet and orbit analysis for the SRC for the RIKEN RI beam factory has been carried out. Combination of the superconducting main coil, superconducting trim coils and normal conducting trim coils can generate isochronous field for various ions within ±0.01 % errors to the isochronous condition. The axial betatron frequency is set between 1.0 and 1.5 in order to avoid crossing the ν_z=1 and ν_z=1.5 resonance lines. Estimation of the risk that working paths lie near the resonance lines and further optimization are under way.

References

[1] Y. Yano et at., "Progress of RIKEN RI Beam Factory Project", Proc. 1996 European Part. Accel. Conf., Sitges (Barcelona) (1996) 536.
[2] A. Goto et al., "Superconducting Ring Cyclotron for the RIKEN RI Beam Factory", this meeting.
[3] Vector Field Limited. Oxford, England.
[4] T. Kawaguchi et al.,"Design of the Sector Magnets for the RIKEN Superconducting Ring Cyclotron", Proc. 1997 Part. Accel. Conf., Vancouver, to be published.
[5] T. Kubo et al.,"Design of a Model Sector Magnet for the RIKEN Superconducting Ring Cyclotron", this meeting.