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Design Study of the Injection and Extraction Systems of the RIKEN Superconducting Ring Cyclotron

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Abstract

A six-sector superconducting ring cyclotron (SRC) is being constructed as a primary post accelerator of the existing accelerator complex for the RIKEN RI beam factory. In the SRC some superconducting magnets with high performances will be used for beam injection and extraction. Design study and R&D of them are described along with brief description of the outline of the systems.

1 Introduction

At RIKEN has started the construction of the RI beam factory[1], which allows us to provide the world's most intensive RI beams at energies of several hundreds MeV/nucleon over the whole range of atomic masses by the projectile fragmentation process. An intermediate-stage ring cyclotron (IRC) and a six-sector superconducting ring cyclotron (SRC) are designed to boost the energy of the ion beams available from the existing RIKEN Ring Cyclotron (RRC)[2]. The extraction energies of the SRC beams are 400 MeV/nucleon for light ions such as carbon and 150 MeV/nucleon for heavy ions such as uranium with an intensity of 1pμA. Injection energies (E_{inj}) and extraction energies (E_{ext}) for three kinds of ion beams are shown in Table 1.

	Charge	Einj (MeV/nucleon)	Eext (MeV/nucleon)
^{16}O	8	127	400
^{84}Kr	30	103	300
^{238}U	59	58	150

Table 1 Energies of the injected and extracted beams in the full power operation of the SRC.

2 Overview of the systems

Figure 1 shows the trajectories of injected and extracted beams in the SRC consisting of such as six sector magnets [3] and four acceleration resonators. The beams are injected through one of the magnetic valleys into the central region of the SRC, and then radially guided to their first equilibrium orbits. The transport system for beam injection consists of seven bending magnets (BM1, BM2, QB1, QB2, BM3, BM4, BM5), three magnetic inflection channels (MIC1 and MIC2), and an electrostatic inflection channel (EIC). The EIC is placed at the position where the trajectories of injected beams finally match with the first equilibrium orbits. The EIC has a small hole through which the injected beams can pass. The MIC's are inserted in the gap between the pair of poles of the sector magnets to increase the bending power of the sector field locally. The bending magnets except the BM1 and the BM2, which have large bending angles, are mainly used for matching of the different trajectories that change depending on the accelerator condition as discussed later. The transport system for beam extraction consists of two bending magnets (EBM1, EBM2), three magnetic deflection channels (MDC1, MDC2, and MDC3) and an electrostatic deflection channel (EDC). Beam extraction starts at the EDC, which is placed in the magnetic valley opposite to that for the EIC. The MDC's are inserted in the gap between the pair of poles of the sector magnets to decrease the bending power of the sector field locally. The EBM is divided into two magnets so that the injected beams can pass through the gap between the two magnets as well as the extracted beam can be tuned easily.

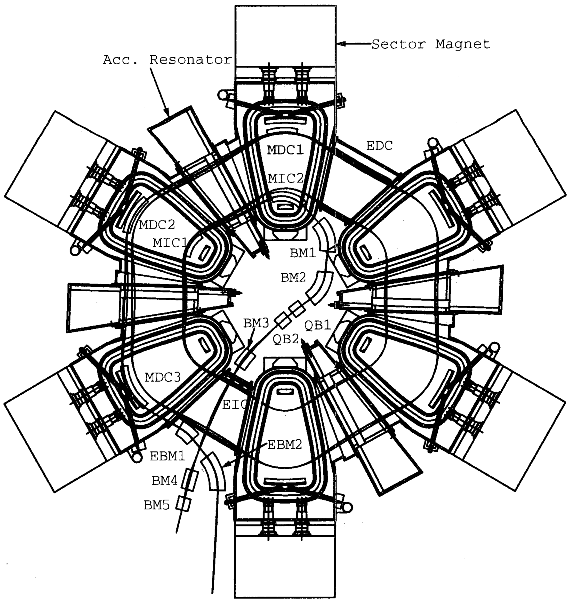

Fig. 1 A schematic layout of injection and extraction elements for the SRC along with trajectories of the injected and extracted beams.

	Radius (cm)	Angle or Length (°) or (cm)	B or E (T) or (kV/cm)	$\Delta B/\Delta x$ (T/m)	Δx (mm)
EIC	>1000	<5.83	100	-	-
MIC1	113	45.5	0.3	-	5
MIC2	96	69.3	1.1	~1	13
BM1	121	50.5	4.5	~0.7	6
BM2	121	50.5	4.4	~0.7	7
QB1	1306	1.75	0.2	~6	3
QB2	744	3.09	0.2	~6	1
BM3	-	64	1	-	60
BM4	-	64	1	-	60
BM5	-	41	0.5	-	17
EDC	>2000	<6.09	105	-	-
MDC1	186	29.7	0.13	-	4
MDC2	192	38.2	0.25	-	12
MDC3	195	45.3	0.31	-	18
EBM1	169	19.7	4.1	-	14
EBM2	169	39.5	4.2	-	12

Table 2 Parameters of the injection and extraction elements and the change in the radial position (Δx) of the trajectories obtained from the numerical analysis. Straight elements are given in length instead of in angle.

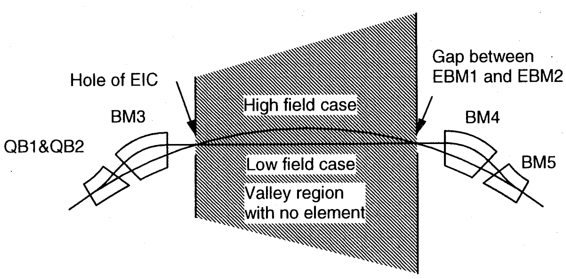

Fig. 2 Concept of matching of trajectories.

The radial-injection method as shown in Fig. 1 is the most straightforward one adopted in many ring cyclotrons. However, to apply the method on the SRC is difficult compared with room-temperature ring cyclotron, because a strong negative fringe field exists in the valley and central region of the SRC and so the beam trajectory strongly depends on the acceleration condition. In order to accept the changes in the beam trajectory, the elements should be movable or have a large bore. We have adopted the latter method for the elements, except for the EIC and the EDC, which are required to move by as large as 10 cm at the maximum in the radial direction. It is important in the design to make the change of the beam trajectories inside the elements (Δx) as small as possible. In the numerical analysis of the injection, we concentrated our effort on minimising them. Results obtained are shown in Table 2, together with the parameters of the elements.

Figure 2 shows the concept of matching of the trajectories which have different curvature in the valley region where no element can be installed. The Δx values of the BM3 and the BM4 become as large as about 60mm, when keeping the differences at the EIC and the gap between the EBM1 and the EBM2 as small as possible. Some elements (QB1, QB2, MIC2, BM1 and BM2) need to generate quadruple fields to match the phase profile of the injected beam to the eigen-elipse of the SRC by keeping beam sizes small enough in the transport line. Optimization of the focusing elements is in progress.

3 Elements for the systems

All the elements of the injection and extraction systems are categorised to five groups as shown in Table 3. The elements of Group 1 and 2 are similar to those used in the RRC. The elements of Group 5 are comparatively easy to construct and realise the required performances because they are straight and their required fields are low. The elements of Group 3 and 4 are difficult and need many R&D works, because their coils are curved and required fields in the coils are as high as 6 T and because the spaces for the installation are limited.

Gr.	Characteristics	Elements
1	Electrostatic channel	EIC, EDC
2	Normal conducting Magnetic Channel	MIC1, MDC1-3
3	Superconducting Magnetic Channel	MIC2
4	Superconducting Bending Magnet (high field)	BM1-2, EBM1-2
5	Superconducting Bending Magnet (large bore)	BM3-5,QB1-2

Table 3 Five groups of the elements for the injection and extraction systems.

4 Design and R&D program of MIC2

Main parameters of the MIC2 are listed in Table 4. It needs to generate a magnetic field of about 1T on the base field of 4 T of the sector magnet, along the beam trajectory which is curved with a curvature of about 1m. Figure 3 shows the proposed cross section and 3D-view of the coil structure. Six current sheets (center coils and half of side coils) located near the beam axis generate a magnetic field in the beam bore, and the other two current sheets (half of side coils) generate a field to cancel the fringe field from the

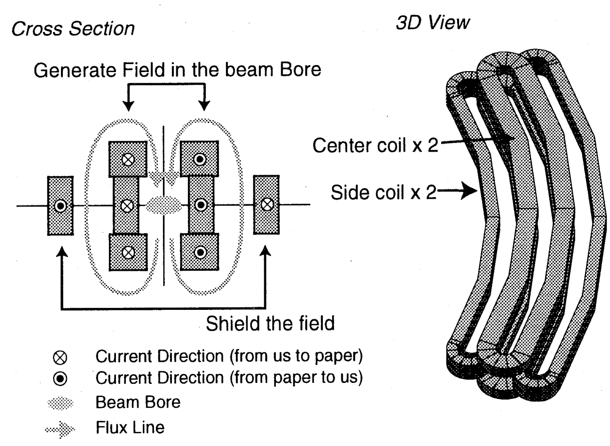

Fig. 3 Coil structure of the MIC2.

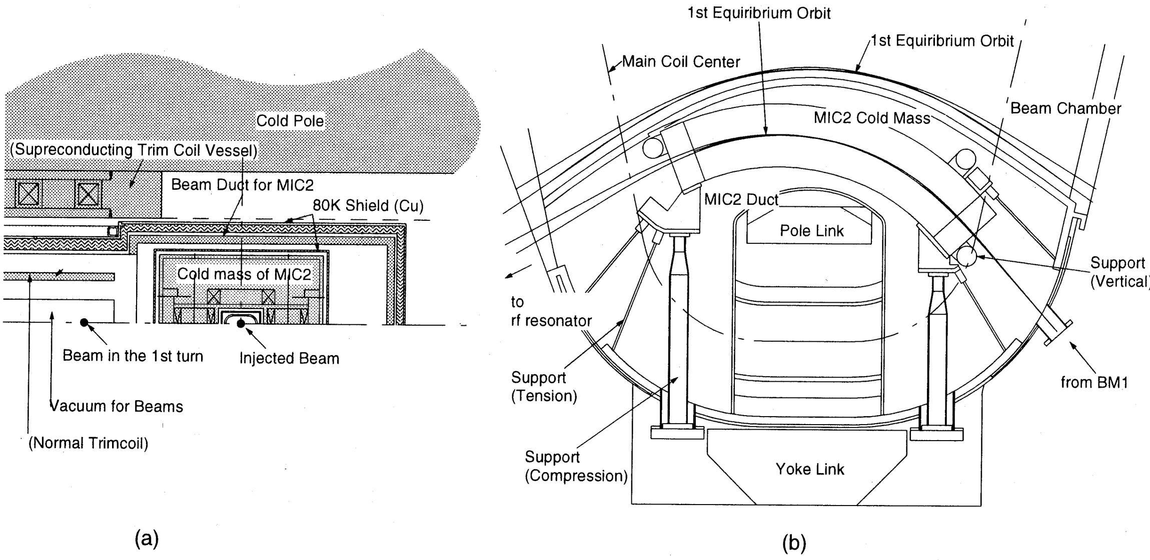

Fig. 4 MIC2 Installation: (a) cross sectional view and (b) plan view.

Item	Value
Type	Iron free, Active shield type
Coil configuration	Center coil, Side coil, Gradient coil (not shown in Fig. 3)
Required field	~ 1.12 T
Required gradient field	About 2T/m
Maximum field in the coil	6.12T
Homogeneity	1 x 10^{-3}
Beam bore	40 (H) x 30 (V) mm^2
Radius	955 mm
Angle	73 degree
Fringe field at the 1st. E.O.	< 100 gauss

Table 4 Main specifications of the MIC2.

six current sheets. Such configurations of the current sheets can realise the structure of coils that need not be bent up at the ends of the channel, which makes coil winding and coil support easier. The cold mass has been designed not to be installed in the cryostat of the sector magnet but in the beam duct so that the MIC2 can be maintained without warm-up and cool-down of the cold mass of the sector magnet which takes about 2 months. A cross section and horizontal view are shown in Fig. 4. The isolated beam duct from the cryostat of the sector magnet is made for the MIC2. The space for the cold mass of the MIC2 is very narrow: 210mm and 230mm in the vertical and horizontal directions at the minimum, respectively, including the space for the thermal insulation.

The R&D program for the MIC2 has three steps as follows:

1. Test of the test center coils with a full scale,
2. Test of the prototype magnet of the MIC2 in no base field, and
3. Test of the prototype magnet of the MIC2 in the base field from the model sector magnet.

The test center coils simulate the center coils of the real MIC2. Their coil size, winding method/winding structure, support structure and so on were designed to be as close as possible to those of the real one. The test center coils will be tested in the field of about 4 T generated with a bias split coil in order to simulate the real operation. The following items will be checked:

1. Structure of coil block (with/without He channels),
2. Winding method/winding structure, and
3. Support structure.

References

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