DESGIN STUDY OF THE INJECTION AND EXTRACTION SYSTEMS FOR THE RIKEN SUPERCONDUCTING RING CYCLOTRON

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Abstract

In the RI beam factory project,[1] an intermediate-stage ring cyclotron and a six-sector superconducting ring cyclotron (IRC and SRC)[2, 3] are designed to boost the energy of the ion beams available from the existing RIKEN Ring Cyclotron (RRC). The output energies designed to the SRC are 400 MeV/u for light ions such as carbon and are 150 MeV/u for heavy ions such as uranium. In the present report, we describe the recent status of design study of the injection and extraction systems for the SRC.

1 INJECTION SYSTEM

The injection energies (E_{inj}), required to obtain the designed output energies (E_{ext}), for three kinds of ion beams, are shown in Table 1. Figure 1 shows an example of the trajectories of injected beams in the SRC. The beams are injected through one of the magnetic valleys into the central region of the SRC, which are then radially guided to their first equilibrium orbits. The transport system consists of four bending magnets (BM1, BM2, BM3 and BM4), three magnetic inflection channels (MIC1, MIC2 and MIC3), and an electrostatic inflection channel (EIC). The MICs 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 EIC is placed in the position where the trajectories of injected beams match finally with the first equilibrium orbits. The radial-injection method as shown in Fig. 1 is the most straightforward one adopted in many ring cyclotrons. However, to apply the same method on the SRC is more difficult than on the normal conducting ring cyclotron, because a strong negative fringe field exists in the valley region for the SRC and so the beam trajectory strongly depends on the acceleration condition.

	Charge	E_{inj} (MeV/u)	E_{ext} (MeV/u)
^{16}O	8+	127	400
^{84}Kr	30+	103	300
^{238}U	59+	58	150

Table 1: Energies of the injected and extracted beams at the full- power operation of the SRC.

In order to accept the changes in the beam trajectory, the elements should be movable or have a large bore. We adopted the latter method for the elements, except for the EIC, which is required to move as large as 10 cm at the maximum in the radial direction. It is important to make the change of the beam trajectories inside the elements as small as possible. In the numerical analysis of the injection orbits[4], we concentrated our effort on minimizing them (Δx). Obtained results from such an analysis are shown in Table 2, together with their parameters.

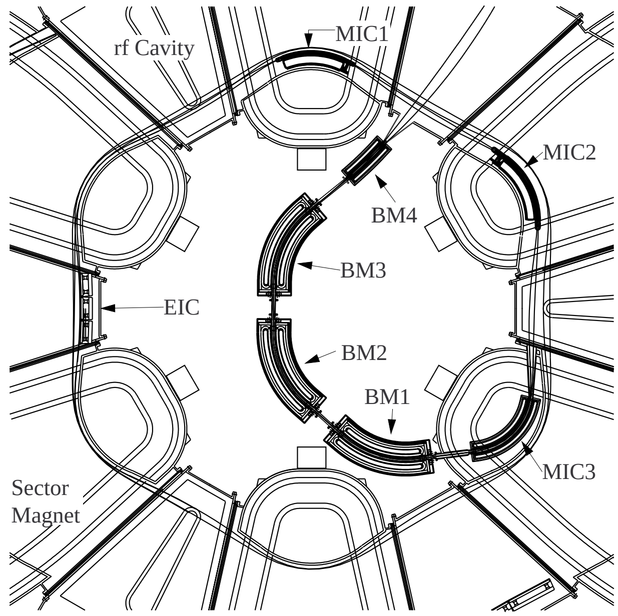

Figure 1: A schematic layout of injection elements for the SRC, and possible trajectories for the injected beam.

1.1 BMs

The BM1, BM2, BM3 and BM4 are required to be superconducting magnets in order to produce the required magnetic fields. The strong stray fields from the sector magnets make these bending magnets difficult to be constructed, because we can not use an iron yoke for magnetic shielding. The total flux of the stray field in the center region of the SRC is large enough to saturate the iron. Thus, we adopted active-shield-type magnets for the BMs although more magnetic motive force is needed than the case of an iron-shield-type magnet.

The specifications of BM1 are listed in Table 3. The space available for the BM1 is verly limited: the BM1 has a space of as small as about 20 cm in the radial direction. In the coil-end region coil supports and cryostat walls need to be accommodated within the space of about 10 cm. In the design of the BM1 magnet, mainly the following two

	Radius (cm)	Angle (deg.)	B or E (max.) (T) or (kV/cm)	Δx (cm)
EIC	–	–	95	10
MIC1	111	46.5	0.18	1.0
MIC2	110	52.5	0.27	1.2
MIC3	87	73.9	1.5	1.2
BM1	132	52.0	4.02	0.9
BM2	130	52.0	3.92	0.7
BM3	128	52.0	3.96	0.5
BM4	492.5	7.0	-0.8,+0.7	2.3

Table 2: Parameters of the injection elements and changes (Δx) in the trajectories obtained from the numerical analysis of injection orbits.

points were taken care: One is that coil structures should be simple because non-straight coils are difficult to wind and the other is that effective length of the field should be as long as possible compared with the real coil length. The proposed coil structures are shown in Fig. 2. This structure has no bend-up in the coil end and the effective length of the field is only 6 cm shorter than the real coil length. Magnetic field analysis[5] show that the superconducting coils can produce the required field with the current less than 50% of the critical current, and that the BM1 can be installed in the limited radial space. Figure 3 shows a schematic drawing of the BM1 on the due position of the SRC. In the near future, the model of the BM1 will be made to test this design.

Item	Value
Type	Iron free Active shield
Maximum field	4.02T
Homogenity	1×10^{-3} /cm^2
Beam Bore	40 (Horizontal) × 20 (Vertical) mm^2
Radius	1320mm
Angle	40deg.
Fringe Field	± 20 cm
Space limit in the radial direction	about ± 20cm
Space for the coil end region	about 10cm

Table 3: Main specifications of the BM1.

1.2 MICs

The MIC1 and MIC2 are normal conducting magnetic channels. Several types of devices can be used as the MIC, for instance, an iron shim, septum coils or a combination of the shim and septum coils. The use of the septum coils is essential for our machine since the magnetic field inside the

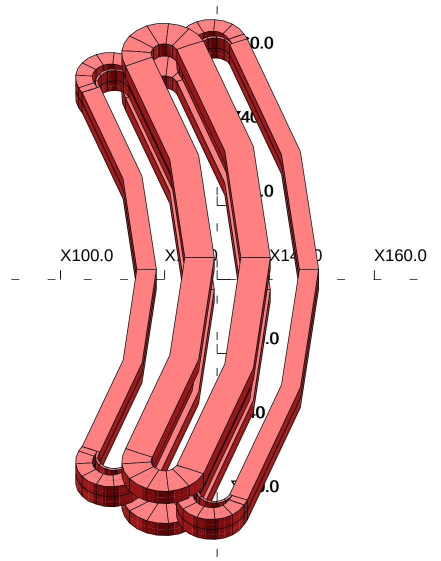

Figure 2: Coil structure of the BM1

MIC must be adjusted in a wide range from low to a considerably high value in accordance with the wide variety of the accelerated particles and energies. Iron shim is not used since uniformity of the field can not be obtained with it in the region of more than 2 T. Figure 4 shows a schematic drawing of the MIC1. Magnetic analysis for these two elements showed that about 20 turns of coils can produce the requied fields of the MIC1 and MIC2.

The MIC3 is the superconducting magnetic channel. The coil structure is under study. This superconducting channel is the most difficult among the superconducting injection elements of the SRC since the curvature is small and the maximum field in the coil is high. A model of the channel will be made to test feasibility of the channel.

1.3 EIC

The EIC needs to move by about 10 cm in the radial direction and vary its curvature. The channel having three divided structres shown in Fig. 5 has been proposed. Its gap is 10 mm and its field is 95 kV/cm. The maximum EV value is confined to be 9500 kV^2 /cm well below the critical value of 15000 kV^2/cm for the sparkover. Conventional stepping moters can not be used to move the EIC because the magnetic field at the EIC is more than 0.1 T. Tests of the oil cylinder for this purpose are under study.

2 EXTRACTION SYSTEM

Examples of the extraction orbits is shown in the Fig. 5 of[4]. The optimization of the extraction trajectories is in progress. The elements similar to the injection system will be used for the extraction system.

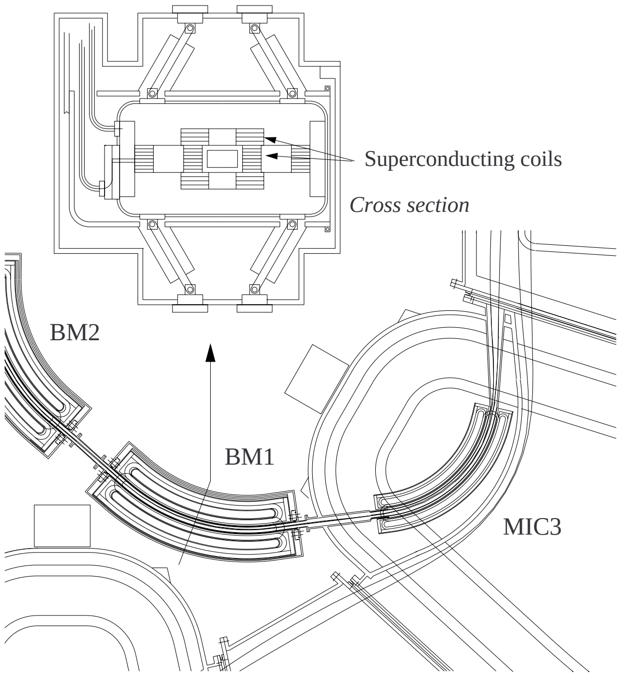

Figure 3: Location of the BM1 in the SRC together with its cross section. Injection and the first equilibrium orbits for $^{16}O^{8+}$ (200 MeV/u) and $^{238}U^{58+}$ (150 MeV/u) are also shown.

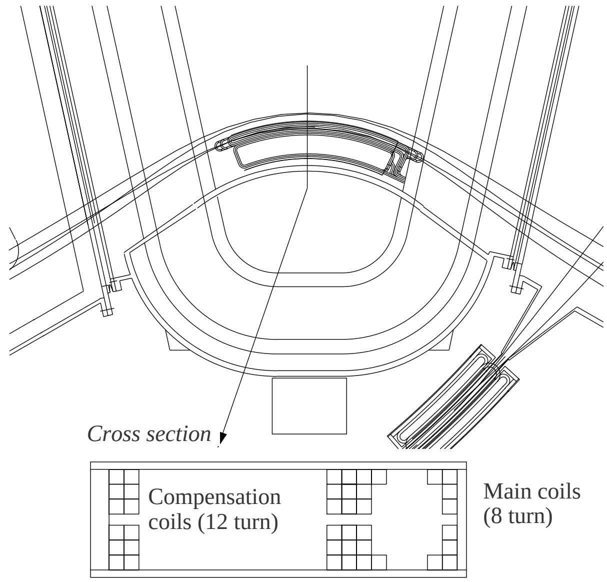

Figure 4: Location of the MIC1 together with its cross section. Injection and the first equilibrium orbits for $^{16}O^{8+}$ (200 MeV/u) and $^{238}U^{58+}$ (150 MeV/u) are also shown.

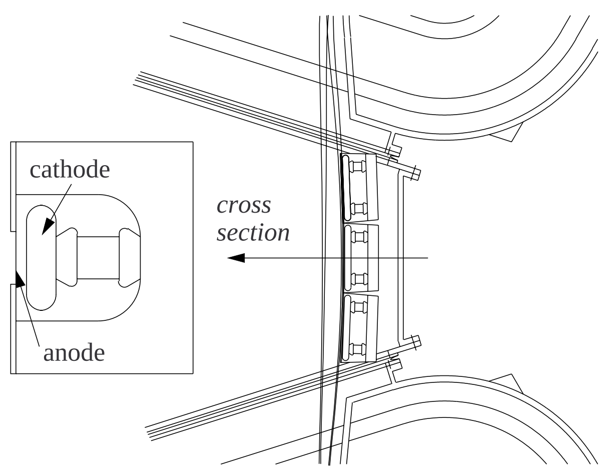

Figure 5: Location of the EIC together with its cross section. The first and the second equilibrium orbits for $^{16}O^{8+}$ (200 MeV/u) and $^{238}U^{58+}$ (150 MeV/u) are also shown.

3 REFERENCES

[1] Y. Yano *et al.*, 'RIKEN RI-Beam Factory project', in this proceedings.

[2] T. Mitsumoto *et al.*, 'Orbit Analysis for the RIKEN Superconducting Ring Cyclotron', in this proceedings.

[3] T. Kawaguchi *et al.*, 'Design of the Sector Magnets for the RIKEN Superconducting Ring Cyclotron', in this proceedings.

[4] S. Fujishima *et al.*, 'Numerical Analyses of the Injection and Extraction Trajectories for the RIKEN Superconducting Ring Cyclotron', in this proceedings.

[5] T. Tominaka *et al.*, 'Design Study of the Injection and Extraction Systems for the RIKEN Superconducting Ring Cyclotron', in this proceedings.