Analysis of the Injection and Extraction Systems for the RIKEN Superconducting Ring Cyclotron

Shiro FUJISHIMA, Hiroki OKUNO, Akira GOTO, and Yasushige YANO
RIKEN (The Institute of Physical and Chemical Research)
2-1, Hirosawa, Wako-shi, Saitama 351-0198, Japan

Abstract

Design of the Injection and Extraction Systems for the RIKEN Superconducting Ring Cyclotron (SRC) is in progress. Purpose of present analysis is to optimize the layouts and specifications of the injection and extraction elements in the SRC. Lot of care was taken especially to minimize not only the required fields of the elements but also the differences of trajectories in the elements.

1 Introduction

The sector magnets of the SRC generate strong field of 4.3 T at the maximum in the magnets, and also generate stray field in the valley originated from saturation of the iron yokes. This stray field gets up to -0.6 T at the maximum and depends non-linearly on the magnetic rigidities of the beams. Thus, the trajectories of various beams differ considerably from each other. The difference of trajectories requires wide bore of the element. Besides, the injection and extraction elements should be installed in a small space limited with the sector magnets, RF-resonators, and vacuum chambers. Because of the space limitation and high rigidity of the beam, the injection and extraction elements should generate considerably high fields. These difficulties make the design of the injection and extraction systems quite challenging.

2 Property of the beams

Table 1 shows the energies and magnetic rigidities of three typical beams. The beam of $^{16}O^{7+}$ (1) has the lowest magnetic rigidity. On the other hand, the beam of $^{238}U^{58+}$ has the highest one. Between these two beams, the difference of trajectories is most remarkable. The beam of $^{16}O^{7+}$ (2) has the highest electric rigidity.

Table 1
Energies and magnetic rigities of typical beams.

	Energy [MeV/u]		$B\rho$ [Tm]	
	Inj.	Ext.	Inj.	Ext.
$^{16}O^{7+}$(1)	74.2	200	2.89	4.90
$^{16}O^{7+}$(2)	126.7	400	3.83	7.25
$^{238}U^{58+}$	58.0	150	4.57	7.52

3 Method of analysis

At first, magnetic fields of the sector magnets were calculated with a three-dimensional computer code, "TOSCA". But the design of the normal-conducting trim coils of the sector magnets has not been optimized perfectly, so the calculated fields of the sector magnets include about 0.3% of error. Error of the field causes position error to the injection and extraction trajectories. To correct relative position error of the trajectories, the energies of the injection or extraction beams were slightly changed as the length of the first or last equilibrium orbits become equal to the design value, respectively. And then, to trace the beam trajectories, an equation of motion was solved with Runge-Kutta-Gill method. In the calculation, electric or magnetic field of each element was superimposed on the field of the sector magnets.

4 Layouts

Figure 1 shows a schematic layout of the injection and extraction elements, and shows the trajectories of two typical beams of $^{16}O^{7+}$ (1) and $^{238}U^{58+}$. This layout has not been optimized completely, so may be modified partly. Because of the stray field in the valley, two trajectories differ considerably from each other. The injection system consists of six bending magnets (BM1 $\sim$ BM6), two magnetic inflection channels (MIC1 and MIC2), and an electrostatic inflection channel (EIC). The extraction system consists of two bending magnets (EBM1 and EBM2), three magnetic deflection channels (MDC1, MDC2 and MDC3), and an electrostatic deflection channel (EDC). All MICs and all MDCs are installed between upper and lower coils of the sector magnets. The beams from a pre-accelerator are introduced crossing the EIC, so that the EIC should has a hole to pass the injection beams. To minimize the hole diameter, each trajectory was adjusted to cross at the same point on the electrode of the EIC.

5 Specifications

Table 2 and Table 3 show specification of the injection and extraction elements, respectively. The MIC1 and all MDCs consist of normal-conducting coils. On the other hand, the MIC2, all BMs and all EBMs consist of superconducting coils. The BM1 and BM2 have identical structure and size to reduce fabrication cost. For the same reason, the BM3, BM4, BM5 and BM6 are identical. Each magnetic element consists of main dipole coils and compensation coils to suppress fringe field on the first or last equilibrium orbits. Gradient-field-coils are built additionally in the MIC2, BM1 and BM2 to adjust the injection beam envelopes. Length of each element was determined in consideration of the balance between the difference of trajectories in the element and the required field of the element. Table 4 shows the differences of trajectories and bores in the elements.

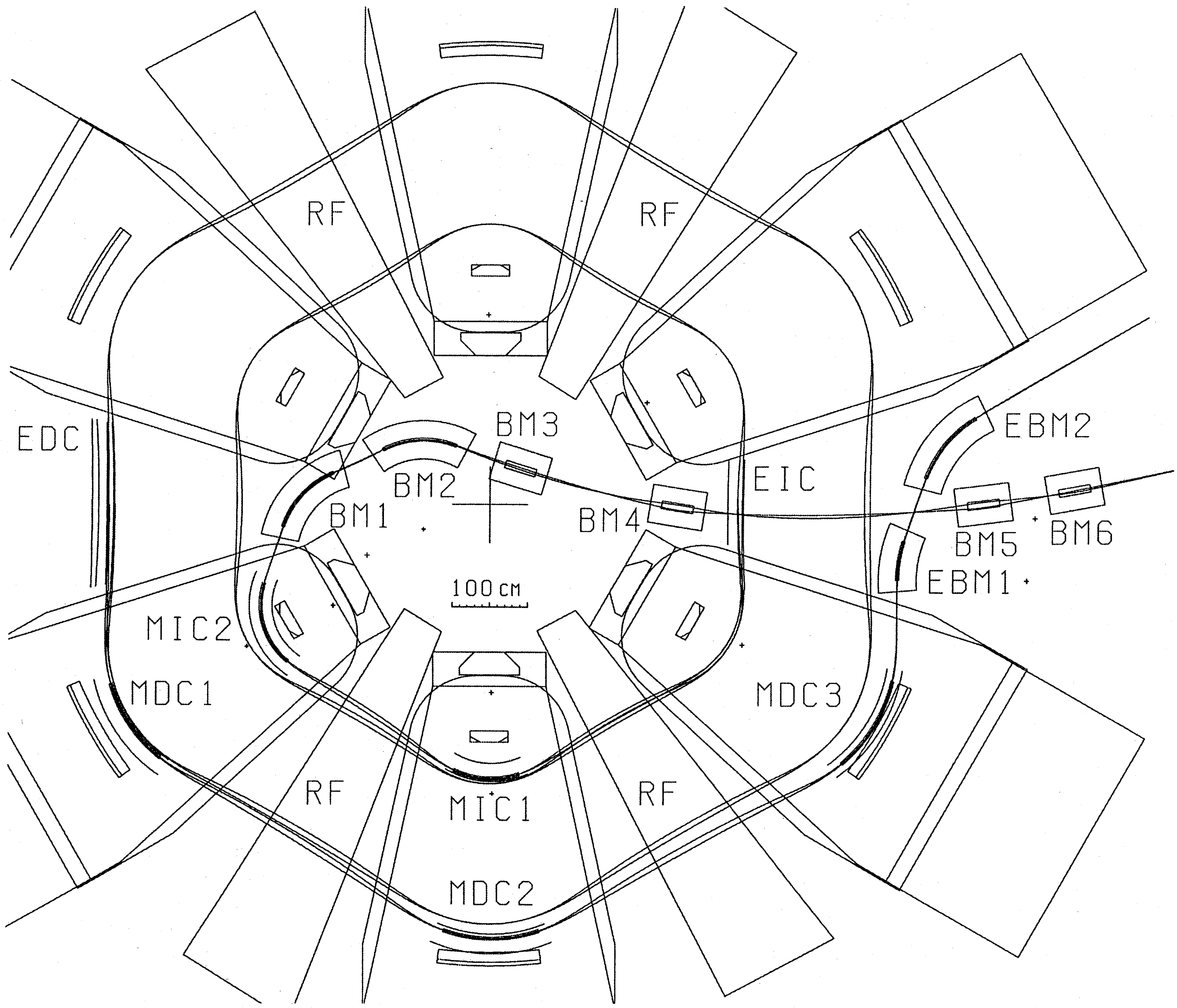

Fig.1 Schematic layouts of the injection and extraction elements and trajectories of two typical beams.

Table 2
Specifications of the injection elements.

	Radius [cm]	Angle [deg.]	Length [cm]	Max. Field [kV/cm], [T]
EIC	1000~4280	variable	101.7	100
MIC1	112.7	45.5	89.5	0.30
MIC2	95.6	69.3	115.5	1.12
BM1	117.0	49.0	100.1	4.70
BM2	117.0	49.0	100.1	4.40
BM3	straight	-	41.9	0.25
BM4	straight	-	41.9	1.36
BM5	straight	-	41.9	0.90
BM6	straight	-	41.9	-1.00

Table 3
Specifications of the extraction elements.

	Radius [cm]	Angle [deg.]	Length [cm]	Max. Field [kV/cm], [T]
EDC	1690~4410	variable	212.5	-105
MDC1	185.0	37.0	119.5	-0.15
MDC2	190.0	39.0	129.3	-0.27
MDC3	203.5	36.8	130.7	-0.48
EBM1	169.4	17.7	52.3	-4.00
EBM2	152.4	39.1	104.0	-4.50

Table 4
Differences of trajectories and bores in the elements.

	Difference [mm]	Bore [mm] Verti. × Horiz.
EIC (movable)	61	12 (Horiz.)
MIC1	5	30 × 35
MIC2 ~ BM2	about 13	30 × 40
BM3 ~ BM6	less than 70	30 × 100
EDC (movable)	75	12 (Horiz.)
MDC1 ~ EBM2	about 13	30 × 40

5.1 MIC1

Horizontal size of the MIC1 is limited with turn separation of 54 mm between the injection trajectories and the first equilibrium orbits. And, on the first equilibrium orbits, fringe fields of the MIC1 should be suppressed less than 100 gauss. Vertical size of the MIC1 is limited with the gap of 60 mm in the beam chamber of the sector magnet. Because of small space for installation, superconducting coils are not available, but the MIC1 should generate comparatively high field and suppress its fringe field with a compensation coil.

5.2 MIC2

Figure 2 shows trajectories in the MIC2. The trajectories in the MIC2 go out at the BM1 side, because magnetic fields of the sector magnet decrease around there. Because of small bending radius of 96 cm, it may be difficult to support inner coils of the MIC2 perfectly. How to wind and support inner coils is the key of stability of superconducting state in the MIC2. Prototype of the MIC2 will be fabricated in this fiscal year.[1]

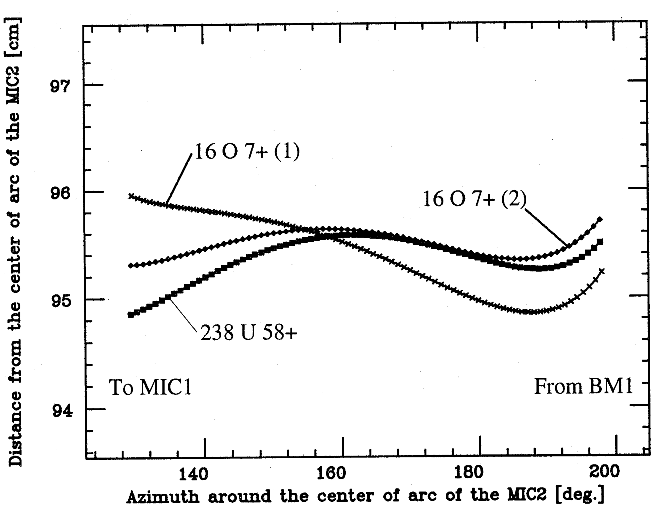

Fig.2 Trajectories in the MIC2.

5.3 BM1 and BM2

Background stray field from the sector magnets is strong especially around the BM1. To prevent undesirous opposite bend of the beams, the distance between the cryostat of the sector magnet and the coils of the BM1 is required as short as possible. For that purpose, no-bend-up coil structure was adopted to minimize the edge size of the BM1.

5.4 BM3 ~ BM6

The injection beams should pass through the small hole on the EIC, and go through a long valley filled with non-linear stray fields, so that the differences of trajectories increase in the BM3, BM4, BM5 and BM6 (BM3-6). To suppress the difference of trajectories as small as possible, the length of the BM3-6 was shortened compared with other magnetic elements. However, the differences of trajectories are still large in the BM3-6. Thus, the BM3-6 have wide horizontal bore.

5.5 EDC

Figure 3 shows trajectories around the EDC. The EDC moves in the radial direction by 75 mm to accept the difference of trajectories. And, the EDC consists of three arcs conected with two hinges to adjust its curvature. Designed E*V value of 13230 $(kV)^2/cm$ is considerably high. Therefore, R&D for the EDC is requierd to establish its feasibility.

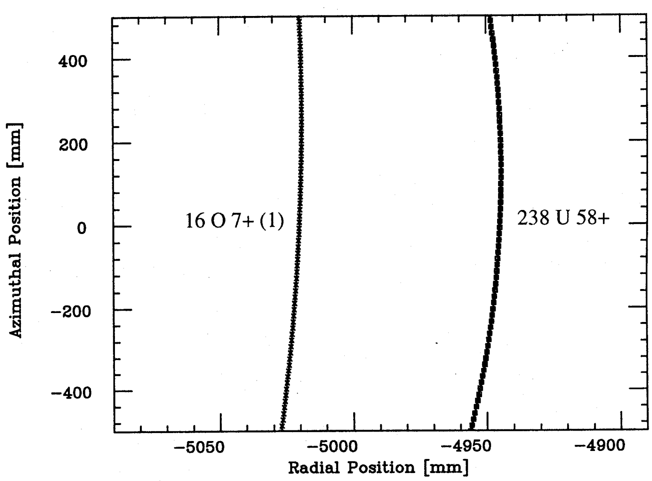

Fig.3 Trajectories around the EDC.

References

[1] H. Okuno et. al., " Design Study for the Injection and Extraction Systems for the RIKEN Superconducting Ring Cyclotron ", in this proceedings.