DESIGN OF THE INJECTION AND EXTRACTION SYSTEMS FOR THE RIKEN SRC

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Abstract

Along with the change of the design of the sector magnets of the RIKEN Superconducting Ring Cyclotron (SRC), the design of the injection and extraction systems for the SRC has also been changed significantly compared to the previous design. The basic layouts and specifications of the injection and extraction elements were determined by numerical analysis of the injection and extraction trajectories. In the analysis, much care was taken in particular to minimize not only the required fields of the elements but also the differences between various beam trajectories in each element.

1 INTRODUCTION

The stray field from the sector magnets depends non-linearly on the magnetic rigidities of the beams, and causes the difference between various beam trajectories in each element. Larger differences in the trajectories require a wider bore of the element.

In the previous design of the SRC, stray field from the sector magnets had got up to -0.6 T at the maximum and had caused large differences in the trajectories[1]. But, in the present design[2], stray field from the sector magnets decreased to about -0.06 T because of the iron yoke covering the SRC, so that the differences in the trajectories also decreased. However, the injection and extraction elements should be installed in a small space limited by the beam chamber or thermal insulating vacuum vessels of the sector magnets, and moreover, should generate sufficiently high fields to bend a rigid beam. Because of these difficulties, it remains a challenge to design the injection and extraction systems.

2 PROPERTY OF THE BEAMS

Table 1: Energies and magnetic rigidities of typical beams

	Energy [MeV/u]		Bρ [Tm]	
	Inj.	Ext.	Inj.	Ext.
^{238}U^{78+}	40.4	100	2.82	4.51
^{238}U^{88+}	115.2	350	4.31	7.94
^{238}U^{49+}	40.4	100	4.49	7.18
^{16}O^{8+}	138.3	455	3.51	6.85

Table 1 shows the energies and magnetic rigidities of four typical beams. The beam of ^{238}U^{78+} (100 MeV/u) has the lowest magnetic rigidity. The beam of ^{238}U^{88+} (350 MeV/u) has the highest magnetic rigidity at extraction, and also has the highest electric rigidity. The beam of ^{238}U^{49+} (100 MeV/u) has the highest magnetic rigidity at injection. In the acceleration of ^{16}O^{8+} (455 MeV/u), stray field from the sector magnets increases to the maximum, because a part of yoke will be detached to strengthen vertical focusing force.

3 METHOD OF THE ANALYSIS

In the first stage of the analysis, magnetic fields of the sector magnets were calculated with a three-dimensional computer code, "TOSCA". However, the calculated fields of the sector magnets include about 0.3% error, because the design of the normal-conducting trim coils of the sector magnets has not been optimized perfectly. This error causes shifts of the injection and extraction trajectories. To compensate them in the analysis, the energies of the injection or extraction beams were slightly changed as the length of the first or the last equilibrium orbit become equal to the design value, respectively. And then, the equation of motion was solved with using the Runge-Kutta-Gill method to trace the beam trajectories.

4 LAYOUTS AND SPECIFICATIONS

Figure 1 shows a schematic layout of the injection and extraction elements, and also shows the trajectories of two typical beams of ^{238}U^{78+} (100MeV/u) and ^{238}U^{88+} (350MeV/u). Because of the suppression of the stray field in the valley, the difference between two trajectories is indiscernibly small in this figure.

The injection system consists of one superconducting bending magnet (SBM), two normal-conducting magnetic inflection channels (MIC1 and MIC2), and one electrostatic inflection channel (EIC). The extraction system consists of one electrostatic deflection channel (EDC), three normal-conducting magnetic deflection channels (MDC1, MDC2 and MDC3), and one normal-conducting bending magnet (EBM).

Because the injection beams are introduced crossing the EIC and EDC, their respective electrodes have holes to pass the beams. To minimize the hole diameter, each trajectory is adjusted with several steering magnets to cross at the same point on the respective electrodes of the EIC and EDC.

Table 2 shows the specifications of the injection and extraction elements. The length of each magnetic element

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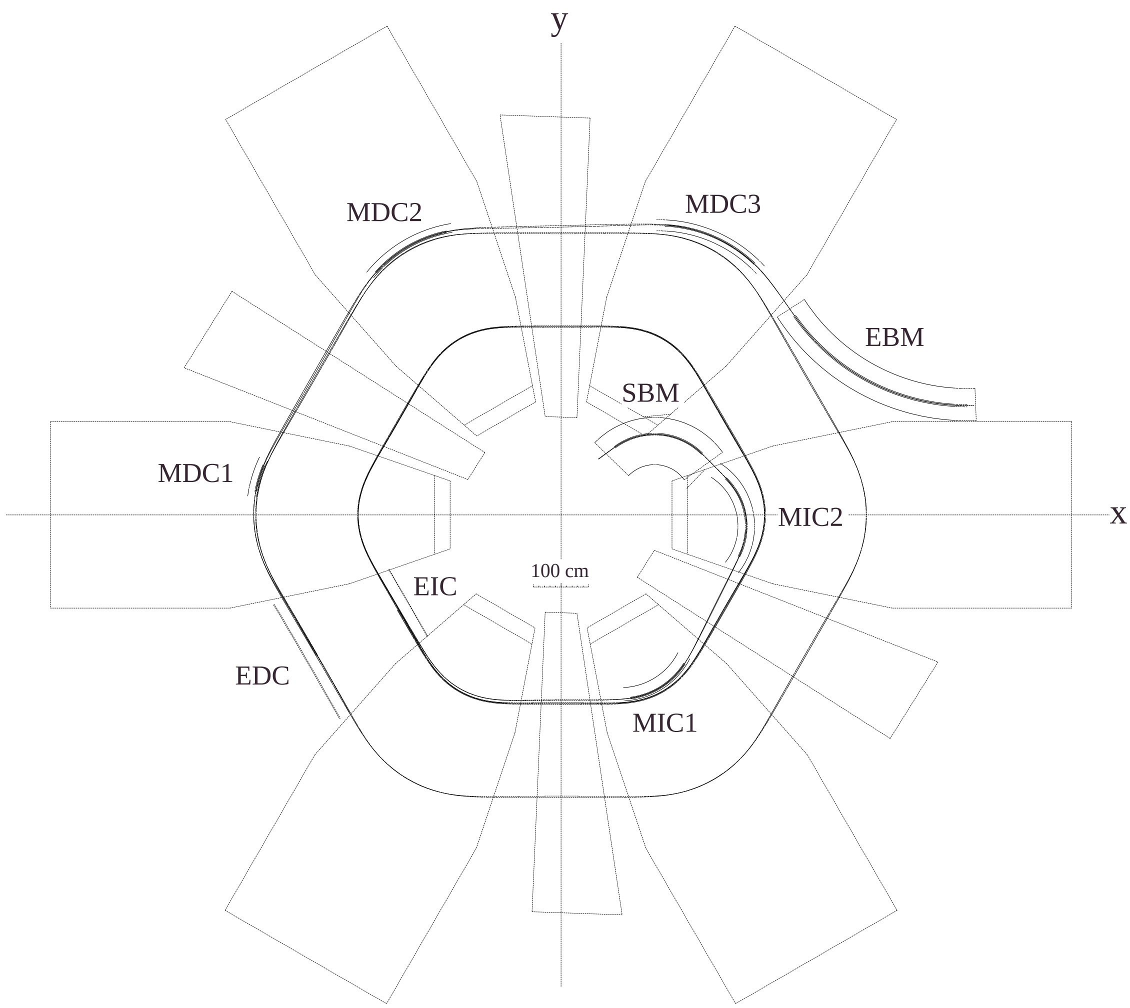

Figure 1: Schematic layout of the elements and trajectories of typical beams

Table 2: Specifications of the injection and extraction elements

	Radius [mm]	Angle [deg.]	Length [mm]	Max. Field [kV/cm], [T]
EIC	variable	variable	1300	90
MIC1	1360	50.4	1196	0.285
MIC2	1200	73.6	1541	0.963
SBM	1206	82.0	1726	3.770
EDC	variable	variable	2280	-90
MDC1	2200	13.0	499	-0.070
MDC2	2320	37.0	1498	-0.198
MDC3	2500	41.2	1798	-0.542
EBM	3800	55.0	3648	-2.039

was determined taking into consideration the balance between the difference of the trajectories in the element and the required field of the element. Each magnetic element consists of not only main dipole coils, but also compensation coils to suppress the fringe field on the first or the last equilibrium orbit. To reduct fabrication cost, and to ensure feasibility, the EBM and all magnetic channels were specified as normal-conducting magnets.

4.1 EIC and EDC

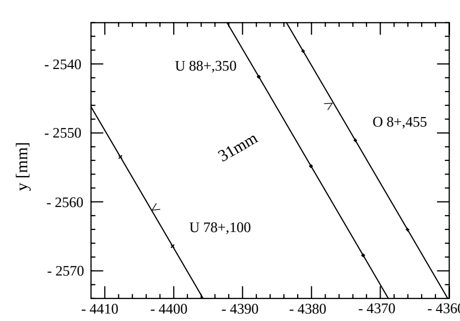

Figure 2: Trajectories in the EDC

Figure 2 shows trajectories in the EDC. Beacuse of the difference between various beam orbits caused by the stray field in the valley, the EIC and EDC should be movable in the radial direction by 18 mm and 31 mm, respectively. Besides, radius of curvature should be adjustable to fit various beam trajectories, for that purpose, the EIC and EDC will consist of three arcs conected with two hinges, respectively.

4.2 MIC1, MDC1 and MDC2

The MIC1, MDC1 and MDC2 are installed in a 90 mm gap of the beam chambers of the sector magnets, and the MIC1 and MDC2 have a similar cross sectional structure. To suppress the required field of the EDC as the same level as the EIC, The MDC1 supplements the bending power of the EDC.

4.3 MIC2 and MDC3

The MIC2 and MDC3 are installed in the atmospheric rooms separated from the beam chambers. Inner height of the rooms are widened to be 140 mm. Required fields of the MIC2 and MDC3 are considerably higher than that of conventional cyclotron. To generate such high fields by normal-conducting coils, special designs were devised by use of iron as efficiently as possible.

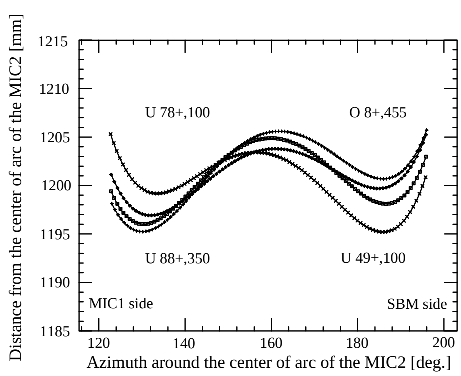

Figure 3: Trajectories in the MIC2

Figure 3 shows trajectories in the MIC2. The trajectories form a "W"-shape, because background magnetic field of the sector magnet decreases at both end-regions of the MIC2.

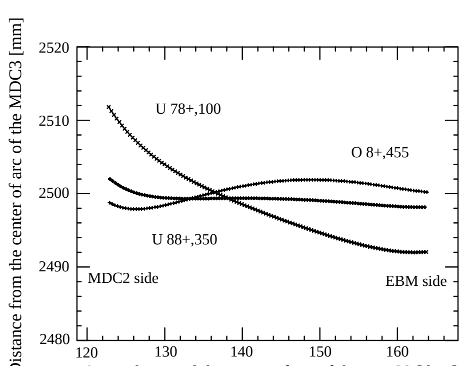

Figure 4: Trajectories in the MDC3

Figure 4 shows trajectories in the MDC3. The MDC3 should accept large difference of the trajectories. Therefore, in the case of acceleration of ^{238}U^{78+} (100 MeV/u), the MDC3 rotates slightly to fit this trajectory.

4.4 SBM and EBM

Because of the required high field and space limitation, the SBM should be a superconducting magnet. Design of the SBM was already completed ahead of other elements, and now the SBM is in the process of fabrication[3].

The EBM has a long arc of 3.65 m, therefore, two pairs of steering coils are built in the EBM to adjust beam trajectories.

5 BEAM ENVELOPES

Figure 5 shows envelopes of the extracted beams of ^{238}U^{78+} (100MeV/u) and ^{16}O^{8+} (455MeV/u). Emittance was assumed to be 2π mm mrad in both vertical and horizontal directions. Optic conditions of the extracted beams can be adjusted by edge-focusing of the EBM.

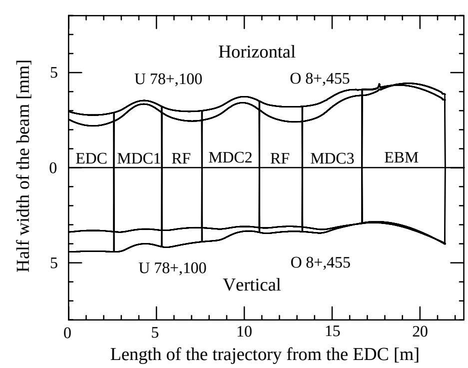

Figure 5: Envelopes of the extracted beams

6 SUMMARY

Basic design of the injection and extraction systems has been completed. Fabrication of the SBM has been started ahead of other elements. Detail designs of remaining elements are now in progress.

7 REFERENCES

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