

DESIGN OF AN EXTRACTION BENDING MAGNET 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. For instance, an extraction bending magnet (EBM) was changed from superconducting type to normal-conducting one. Required maximum magnetic field of EBM is 2.1 T, and EBM has the bore of $\phi 40$ mm and length of 3.7 m. EBM consists of main coils, compensation coils, steering coils, iron pole and yoke, and a built-in beam monitor. Now the design study of EBM is in progress to juggle effective generation of high magnetic field and rational layout of many components.

1 INJECTION AND EXTRACTION SYSTEMS

1.1 Property of the Beams

Table 1 shows the energies and magnetic rigidities of four typical beams. The beam of $^{238}\text{U}^{78+}$ (100 MeV/u) has the lowest magnetic rigidity. The beam of $^{238}\text{U}^{88+}$ (350 MeV/u) has the highest magnetic rigidity at extraction, and also has the highest electric rigidity. The beam of $^{238}\text{U}^{49+}$ (100 MeV/u) has the highest magnetic rigidity at injection. In the acceleration of $^{16}\text{O}^{8+}$ (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.

The stray field from the sector magnets depends nonlinearly 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.

Table 1: Energies and magnetic rigidities of typical beams

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

1.2 Layouts and Specifications

The basic layouts and specifications of the injection and extraction elements were determined by numerical analysis of the injection and extraction trajectories[1]. Figure 1 shows a schematic layout of the injection and extraction elements, and shows the trajectories of typical beams.

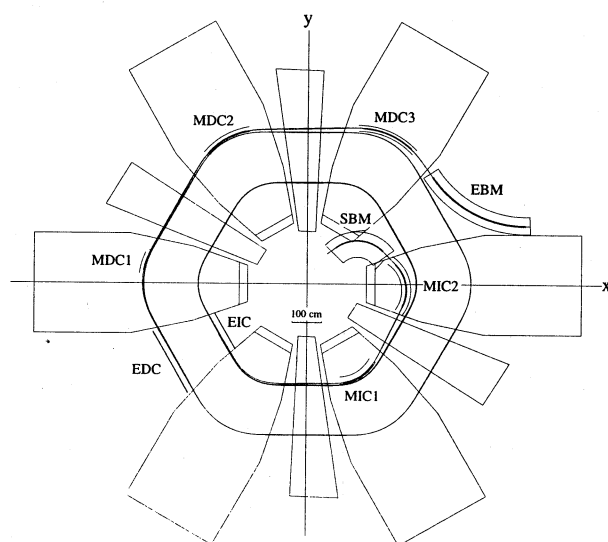


Figure 1: Schematic layout of the elements and trajectories of typical beams

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 extraction bending magnet (EBM). Table 2 shows the specifications of the injection and extraction elements.

2 EXTRACTION BENDING MAGNET

2.1 Design Condition

As a background field, stray field from the sector magnets of SRC exists in the valley. Table 3 shows the averaged background stray fields from the sector magnets, and required fields of EBM. On the acceleration orbits apart 350 mm from the center of EBM, fringe field of EBM should be suppressed less than about 50 Gauss. Required field-uniformity in the bore of EBM is in the order of 10^{-3} .

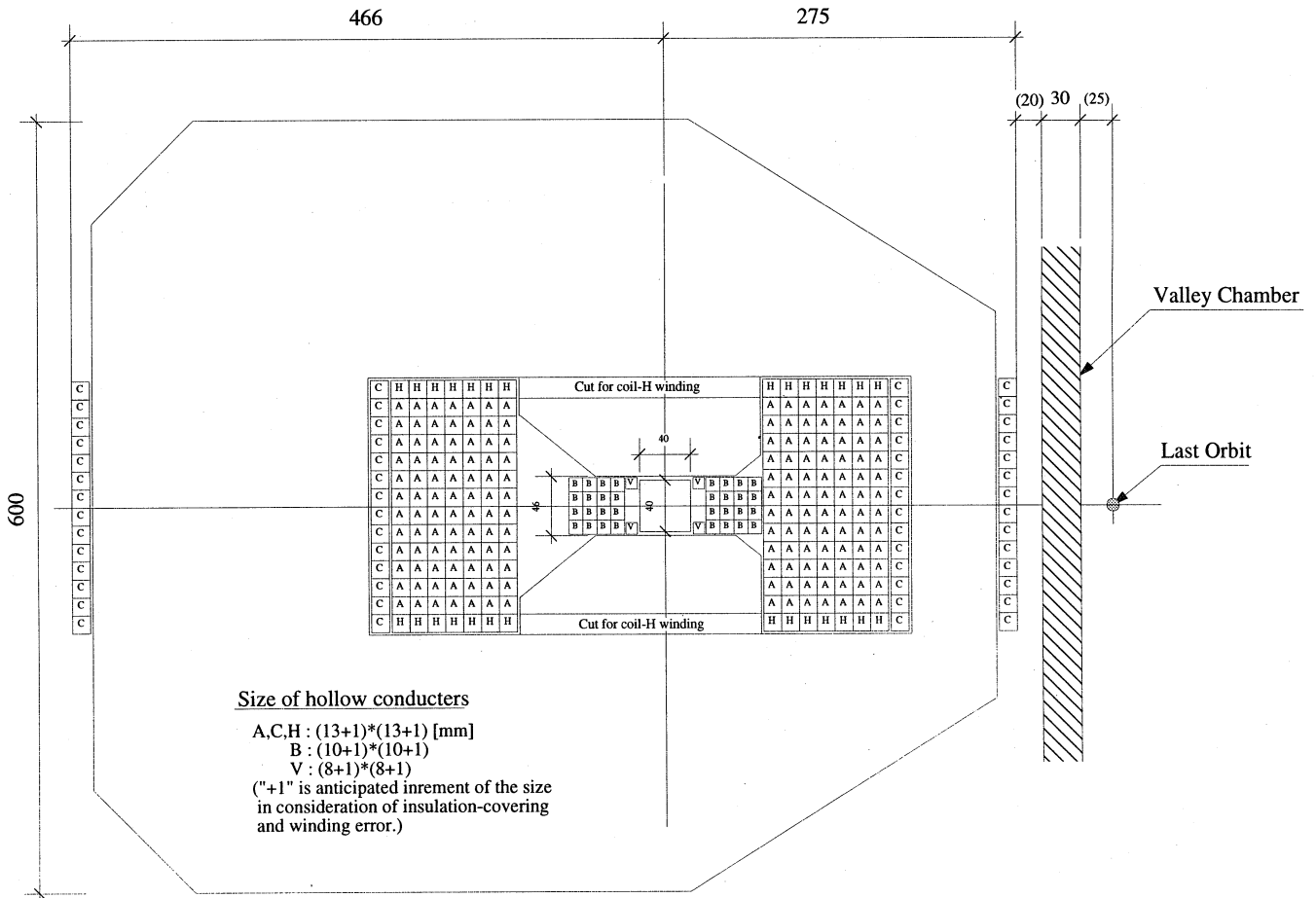


Figure 2: Cross-sectional plan of EBM

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

Built-in vertical and horizontal steerers are also required to generate additional steering field in the order of 100 Gauss.

2.2 Basic Specification

Basic specification of EBM was studied by two-dimensional magnetic field calculation. Figure 2 shows the cross-

Table 3: Background stray field and required field of EBM

	Background [Gauss]	Required [T]
U^{78+} , 100 MeV/u	+50	-1.20
U^{88+} , 350 MeV/u	-450	-2.04

sectional plan of EBM. EBM consists of main coil-A and B, compensation coil-C, horizontal steering coil-H, vertical steering coil-V, and iron pole and yoke. Pole gap is 46 mm. Current of coil-A is the same as coil-B, although size of hollow conductor is different. Each coil-C is wound around the return yoke of EBM. Outer part of coil-C compensate fringe field on the acceleration equilibrium orbits, on the other hand, inner part of coil-C contribute to generate the field in the central region. Coil-H consists of two sets of independent-current coils aligned along the arc of EBM, and contributes not only horizontal steerer but also part of main coil. To wind return part of coil-H, part of iron pole is cut off. Coil-V consists of two sets of independent-current coils inserted in the pole gap. And a beam monitor is installed in the vacancy between these two sets of coil-V.

Table 4: Current density, current, power consumption, winding, and cooling

Coil	Current density [A/mm ²]	Current [A]	Power consumpt. [kW]	Winding	Cooling (turns)×(circuits)
A	3.39	664	42	double-pancake	14×6
B	5.49	664	16	double-pancake	8×2
C	3.70	725	17	solenoid	14×2
H	3.39±0.5	664±98	8±3	single-pancake	14×2
V	±10	±810	0~3	vertically	2×2

Table 4 shows maximum overall current density, current, approximate power consumption, winding style, and cooling unit. Total power consumption is roughly estimated at 90 kW. Temperature rise of cooling water is anticipated to be less than 30 degree with maximum pressure drop of 5 kg/mm².

2.3 Generated Field

Figure 3 shows magnetic flux generated around EBM. Tapered pole was adopted to concentrate magnetic flux in the central region. In consequence, efficiency of field-generation respect to the magnetomotive force is estimated to be good 90 %, in spite of considerable high field required. Right-outside corners of the yoke were chamfered to restrain not only field-fringing of EBM but also absorption of the field on the acceleration orbits.

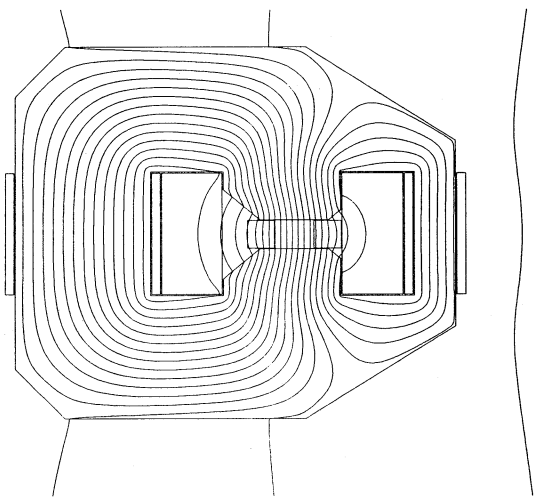


Figure 3: Magnetic flux around EBM

Figure 4 shows overall magnetic field generated by EBM. Figure 5 shows field-uniformity on the median plane in the central region. In case of maximum excitation, field gradient about 27 Gauss/cm is caused by asymmetrical structure of EBM. This field gradient is useful to adjust beam envelopes and momentum dispersions. In the bore of $\phi 40$ mm, field-homogeneity except for the quadrupole component is in the order of 10^{-3} . Fringe field on the acceleration orbits was adequately suppressed less than 35 Gauss.

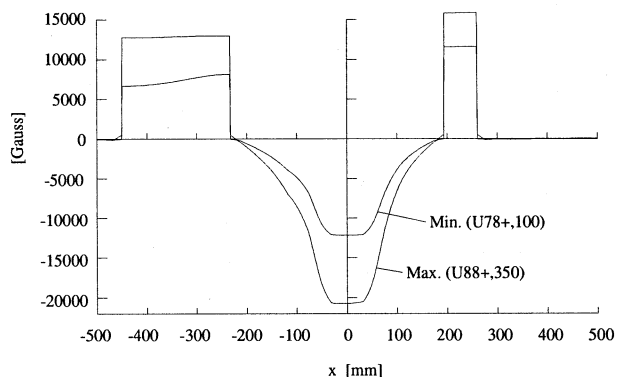


Figure 4: Overall magnetic field generated by EBM

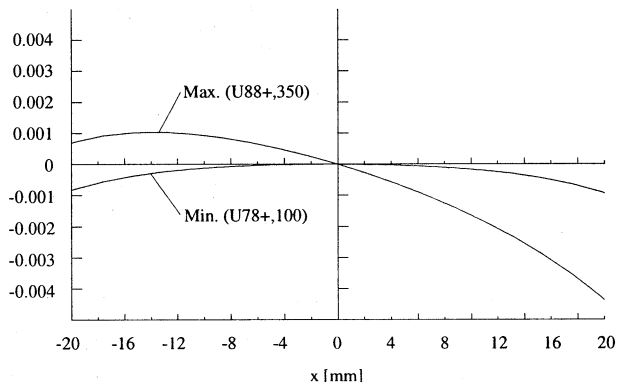


Figure 5: Field-uniformity on the median plane in the central region.

3 SUMMARY

Basic design of the extraction bending magnet for the SRC has been studied. Optimization by three-dimensional field calculation and feasibility study for fabrication are in progress.

4 REFERENCES

- [1] S. Fujishima et. al., "Design of the Injection and Extraction Systems for the RIKEN SRC". CYCLOTRONS 2001, East Lansing, U.S.A., May 2001.