DESIGN OF THE SECTOR MAGNETS FOR THE RIKEN SUPERCONDUCTING RING CYCLOTRON

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Abstract

Design study of the superconducting sector magnets for the RIKEN superconducting ring cyclotron is described. Structures, magnetic forces, superconducting coils and a cryogenic system are discussed. Special features are, the cold pole arrangement, the supporting structure for huge magnetic forces, and the cryogenic stable coils.

1 INTRODUCTION

The RIKEN Superconducting Ring Cyclotron (SRC) is one of the main accelerators for the "RIKEN RI Beam Factory".[1] Six units of superconducting sector magnets[2] are used as the main components of the SRC. Each of sector magnets must generate a maximum magnetic field of 4.5 T in the beam orbital area. We use superconducting main coils and also superconducting trim coils to obtain compactness in size and to save electric power and cooling water. A yoke and poles made of magnetic soft iron are arranged in the sector magnet to reduce ampere turns of the superconducting coils and to minimize a leakage magnetic flux. Table 1 shows main parameters of the sector magnets.

Table 1. Parameters of the sector magnets.

Average radii of beam injection		3.56 m
	extraction	5.36 m
Sector angle of main coil		25 degree
Maximum magnetic field		
	in the beam orbital area	4.5 T
	in the main coil	5.5 T
	in the trim coil	5.0 T
Main-coil's ampere turns per magnet		6.0 MA
Coil cooling method		LHe bath cooling
Magnetic stored energy for 6 magnets		450 MJ
(75 % in air, 17 % in poles, 8 % in yokes)		
Maximum operation currents		
	for main coil	5,000 A
	for trim coil	500 A
Iron weight of 6 magnets		
	poles	216 tons
	yokes	3,630 tons.

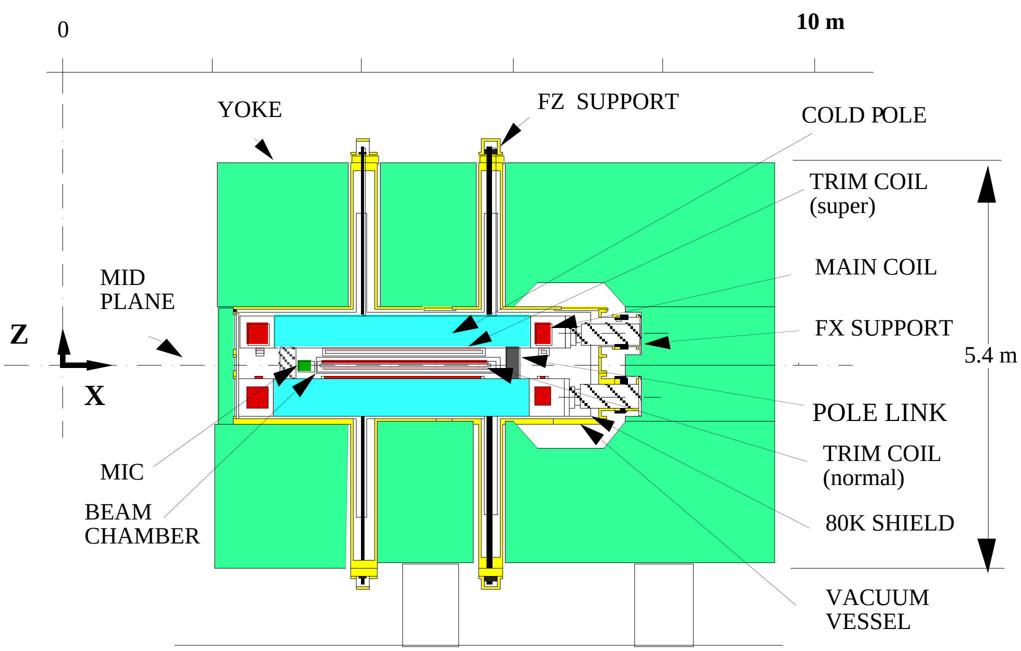

Fig. 1. Cross-sectional view of the sector magnet.

2 STRUCTURES OF THE SUPERCONDUCTING SECTOR MAGNET

Figure 1 shows a cross-sectional view of the sector magnet. Main components of the magnetic elements are superconducting and normal conducting coils, poles and a yoke. We use two kinds of superconducting coils: a pair of main coils and a group of trim coils. Both coils are located upper and lower sides with respect to the mid plane. A group of normal conducting trim coils is also arranged in the upper and lower sides of the beam chamber, to obtain a strictness of isochronous fields.

A special feature is the cold-pole arrangement. This arrangement gives an easier mechanical support against the huge magnetic forces of the main coils, and gives the reductions of ampere-turns and of magnetic forces, compared with a warm-pole arrangement. A vertical magnetic force (Fz) is supported with two pole links which are attached to the upper and lower cold poles.

We have invested two ways of supporting a magnetic shifting force (Fx) in the radial direction. One way is to arrange a pair of cold rings which connect the cold masses (coils and cold poles) of the six sector magnets in 4.5 K region. A problem of the cold ring support system is the central space for the cyclotron. This space is limited for arranging the beam injection elements. The other way is to use large size thermal insulated supports made of high strength material like as titanium alloy, in between the cold mass and the yoke using the outer space of the sector magnet. The problems of this support system are its large heat leak, and its mechanical deflection which causes a position shift of the magnetic field. After optimization for decreasing the shifting force Fx, we have almost decided to use the thermal insulation support system as shown in Fig. 1.

3 MAGNETIC FORCES

Table 2 shows the calculated magnetic forces on the main coil and cold pole at an ampere turns of 6 MA per magnet (or per two coils). The vertical force Fz of 1,154 tons will make a bending deflection of 2 mm in the normal direction to the cold pole of 465 mm in thickness. The shifting force Fx of 104 tons will make the coil position change by 1 mm in the radial direction. This force Fx is generated by the arrangement of six sector coils and the asymmetric configuration of the coils and irons.

4 SUPERCONDUCTING COILS

The superconducting main coil has a triangle shape with two long straight sections of about 3.5 m long. The magnetic force on the main coil is supported by the coil vessel and the cold pole. We apply a cryogenic stabilizing method for the main coil and the trim coil to prevent coil quench. Their average current densities are 34 A/mm^2 and 41 A/mm^2, respectively.

We considered two materials for the stabilizer of the superconducting wire. One was pure copper having rough surface, and another was pure aluminum having flat surface. We have decided to use pure aluminum stabilizer with a reason of the price. Therefore more considerations about the electrical and mechanical properties, the thermal contraction from room temperature to 4.5 K, and the quench protection, were necessary. Specifications of the superconducting wires are shown in Table 3.

5 CRYOGENIC SYSTEM

Figure 2 shows the cooling diagram. Two refrigerators having a capacity of 500 W each at 4.5 K will be used for cooling of the six sector magnets plus the beam injection and extraction superconducting magnets.

Table 2. Magnetic forces exereted on the main coil and the cold pole

unit: ton

	Fx	Fy	Fz
For half main-coil			
No. 1 element	-87	0	-9
No. 2	-166	132	-25
No. 3	-185	940	-254
No. 4	160	205	-84
No. 5	310	21	-115
Sum.	32	1298	87
For one cold-pole	-12	0	-180
For half cold-mass	52	0	-1154
(one main-coil and one cold-pole)			
For one cold-mass (one magnet)	104	0	0

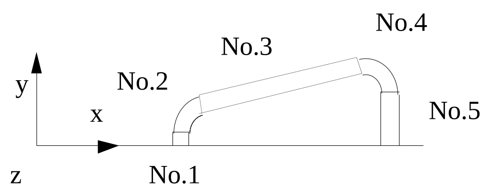

Table 3. Specifications of the superconductors

	[Main Coil]	[Trim Coil]
Max. operation current (A)	5,000	500
Critical current (A) at 6T, 4.5K	10,000	1,000
Cryogenic stabilizing current (A)	6,000 (partial stab.)	550 (full stab.)
Cooling surface ratio	50 %	40 %
Outer dimensions (mm)	8 X 15	2.9 X 3.6
Material	NbTi/Cu-Al	NbTi/Cu-Al
Al/Cu /NbTi section area ratio	17/1/1	15/1/1
Surface treatment	non	non
Total length for 6 magnets (km)	77	47

The cold-mass weight of the six sector magnets is 360 tons, and it will take one and a half months for cooling the cold mass from room temperature to 4.5 K. We expect to operate the superconducting ring cyclotron for more than 6,000 hours a year. Therefore, the cold mass should be kept in low temperature as long as possible. When one refrigerator breaks down, the magnets can be kept at 5 to 6 K with the other refrigerator. We will have one or two days of power off a year for the power system maintenance, and at that time a recovery compressor with an emergency power source will recover the evaporated helium gas to buffer tanks. We will use no liquid nitrogen in this cryogenic system for simplicity of the cooling system.

6 R&D ITEMS

We have measured and plan to the following items for verifying our design before constructing the real sector magnets.

1) Heat flux characteristics of superconductors.

Heat flux characteristics of the main and trim coil conductors, which are important parameters for cryogenic stabilizing, were already measured in liquid helium. The results satisfied the design.

2) Cryogenic stabilizing currents.

The cryogenic stabilizing currents of the main and trim coil conductors will be measured using small circular coils under 6 T magnetic field with a bias superconducting coil in liquid helium.

3) Mechanical properties of aluminum stabilizing superconductor.

We have not enough mechanical property data about aluminum stabilizing superconductor. Tensile strength, fatigue strength, and creep characteristics are being measured using the main coil superconductor.

4) A real-size model magnet.

The biggest R&D item is a real-size model sector magnet. We are now constructing the model magnet. The details are given in Ref. 3.

5) Unbalanced magnetic forces.

Unbalanced magnetic forces in the radial, vertical and azimuthal directions can be calculated with 3-D finite element computer program. But these calculated values are less than 2 % of the total magnetic force. Hence, the accuracy of the calculated value should be carefully considered. We plan to measure these unbalanced forces using three sets of small size sector magnets, each consisting of copper coils, poles and a yokes.

7 SUMMARY

A basic design of the superconducting sector magnet for the RIKEN superconducting ring cyclotron has been carried out. We are currently studying the details and making the optimization, doing many kinds of R&D.

REFERENCES

[1] Y. Yano et al.: ‘RIKEN RI Beam Factory Project’, Proc. of 14th Cyclotrons and Their Applications, 1995.

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[3] T. Kubo et al.: ‘Design of a Model Sector Magnet for the RIKEN Superconducting Ring Cyclotron’, these proceedings.

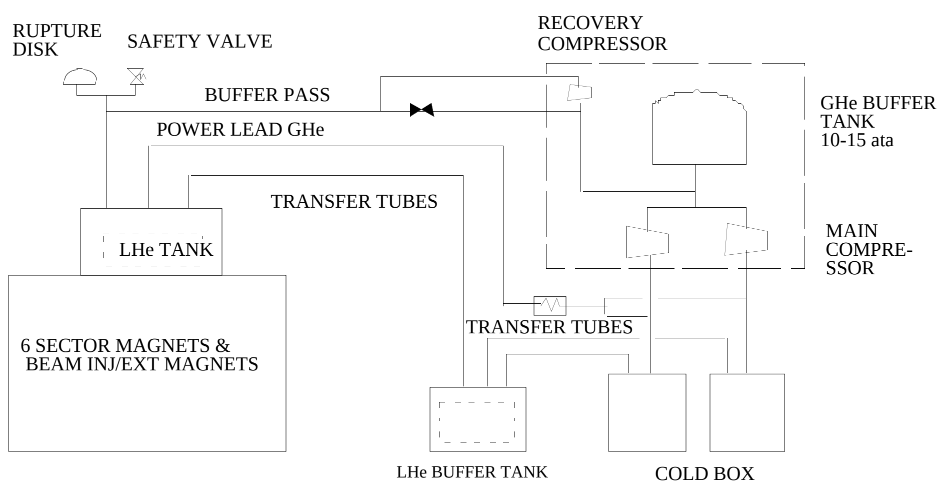

Fig. 2 Cooling diagram for 6 secter magnets and beam injection/extraction magnets