Design Study of Sector Magnet for the RIKEN Superconducting Ring Cyclotron (2)

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Abstract

A conceptual design of the superconducting sector magnet for the RIKEN's future superconducting ring cyclotron is described. A structure, 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 Cyclotrons (SRC-4 and SRC-6) are one of the main accelerators of the " RIKEN RI Beam Factory" [1] . Six units of superconducting sector magnets are used as the main components of SRC-6. Each of sector magnets must generate a maximum magnetic field of 4.5T 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. The yoke and pole made of magnetic soft iron are arranged in the sector magnet to reduce ampere turns of the superconducting coils and to minimize the leakage magnetic flux. Table 1 shows the main parameters of the sector magnets.

2 STRUCTURES OF SUPERCONDUCTING SECTOR MAGNET

Figure 1 shows the section 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 coil are also arranged in the upper and lower side of the beam chamber, to obtain a strictness of isochronous fields. A special feature is the cold pole arrangement. This arrangement gives a mechanical support against the huge magnetic force of the main coils, and gives a decrease of the magnetic force as well as an ampere-turns, compared with a warm pole arrangement. A vertical magnetic force Fz over 1500 tons is supported with two coil-links which are located in between the upper and lower cold poles. We are investigating two ways of supporting a magnetic shifting force Fx of over 300 tons in 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. This cold ring support is shown in Fig. 1. A problem of the cold ring support is the central space for the cyclotron. This space is limited to arrange the beam injection elements. Another 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 thermal insulating support are its large heat leak, and its mechanical deflection which causes a position shift of the field.

Table 1 Parameters of sector magnet.

Average Radii of beam injection,	3.56m,
extraction.	5.36 m.
Sector Angle of main coil	25 degree
Maximum Magnetic Fields	
in beam orbital area,	4.5 T,
in Main coil,	5.5 T,
in Trim coil	5.0 T.
Main Coil Ampere Turns per Magnet	6.0 MA
Coil Cooling Method	LHe bath cooling
Magnetic Stored Energy of 6 Magnets .	450 MJ
(75 % in Air, 17 % in Cold Poles, 8 % in Yokes)	
Maximum Operation Currents	
for Main Coil ,	5000 A,
for Trim Coil.	500 A.
Iron Weights of 6 Magnets	
Cold Poles,	216 tons,
Yokes.	3630tons.

3 MAGNETIC FORCES

Table 2 shows the calculated magnetic forces of the main coil and the cold pole with an ampere turns of 6 MA per magnet (per two coils). The vertical force Fz of 1520 tons is supported with two coil-links, and makes a bending deflection of 3 mm for the cold pole of 445 mm thickness. The shifting force Fx of 340 tons must be maintained with the cold ring or the thermal insulating supports. This shifting force is produced by the arrangement of six sector coils and the asymmetry configuration of the coils and the irons.

4 SUPERCONDUCTING COILS

The main superconducting coil has 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. The average current density of them should be less than 40 A/mm2 and 50 A/mm2, respectively. The specifications of the superconducting wires are shown on Table 3. The copper stabilizer of the main coil conductor will be treated to have rough surface of 0.25mm depth, and also treated with oxidization for increasing a heat flux. For the stabilizer of the trim coil conductor, 4 - nine pure aluminum is applied having no surface treatment. There is a possibility to use 4 - nine aluminum stabilizer instead of copper stabilizer for main coil conductor comparing the mechanical properties, the magnetic resistivity, the temperature rise at coil quench and the price.

5 CRYOGENIC SYSYTEM

Two refrigerators having a capacity of 500 W each at 4.5 K will be used for the six sector magnets and the beam injection / extraction magnets. Figure 2 shows the cooling diagram. We expect to operate the superconducting ring cyclotron for more than 6000 hours a year. The cold mass weight of the six sector magnets is 360 tons, and it will take one month to cool from room temperature to 4.5 K. The cold mass will 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 have one or two days of power off a year for power system maintenance, and at that time a recovery compressor with an emergency power source will recover the evaporated helium gas to the buffer tank. We have no liquid nitrogen in this cryogenic system.

6 CONCLUSION

A design study of the superconducting sector magnet for RIKEN superconducting ring cyclotron has been carried out. The structure, the magnets forces, the superconducting coils, and the cryogenic system has been discussed. We are going to construct a model superconducting sector magnet to verify our design.

REFERENCE

1) Y. Yano et al. : ' Progress of RIKEN RI Beam Factory Project ' , These proceedings.

Table 2 Magnetic forces of main coil and cold pole

unit: ton

for a Half Coil	Fx	Fy	Fz
No. 1 element	-113	0	-67
No. 2	-162	137	-89
No. 3	-180	922	-304
No. 4	170	214	-71
No. 5	345	23	-106
Sum.	60	1296	-637
for a Cold Pole	51	0	-249
for A Half Cold Mass (One main coil and One Cold Pole)	171	0	-1523
for A Magnet (One Cold Mass)	342	0	0

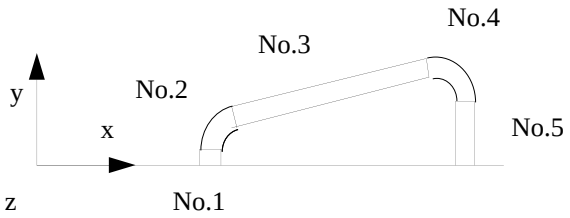

Table 3 Specifications of superconductor.

	[Main Coil]	[Trim Coil]
Max. Operation Current (A)	5000	500
Critical Current (A) at 4.3 K	12000 at 6 T	1200 at 6 T
Cryogenic Stabilizing Current (A)	more than 6000	more than 600
	(Maddock Type)	(Stekley Type)
Outer Dimensions (mm)	7.5 X 14	2.3 X 2.8
Material	Cu / Cu - NbTi	Al / Cu - NbTi
Stabilizer / SC	12.7 / 1.1 / 1	7.3 / 1.1 / 1
Surface treatment	0.25 mm rough surface and Oxidization	Non
Total Length for6 Magnets	77 km	47 km

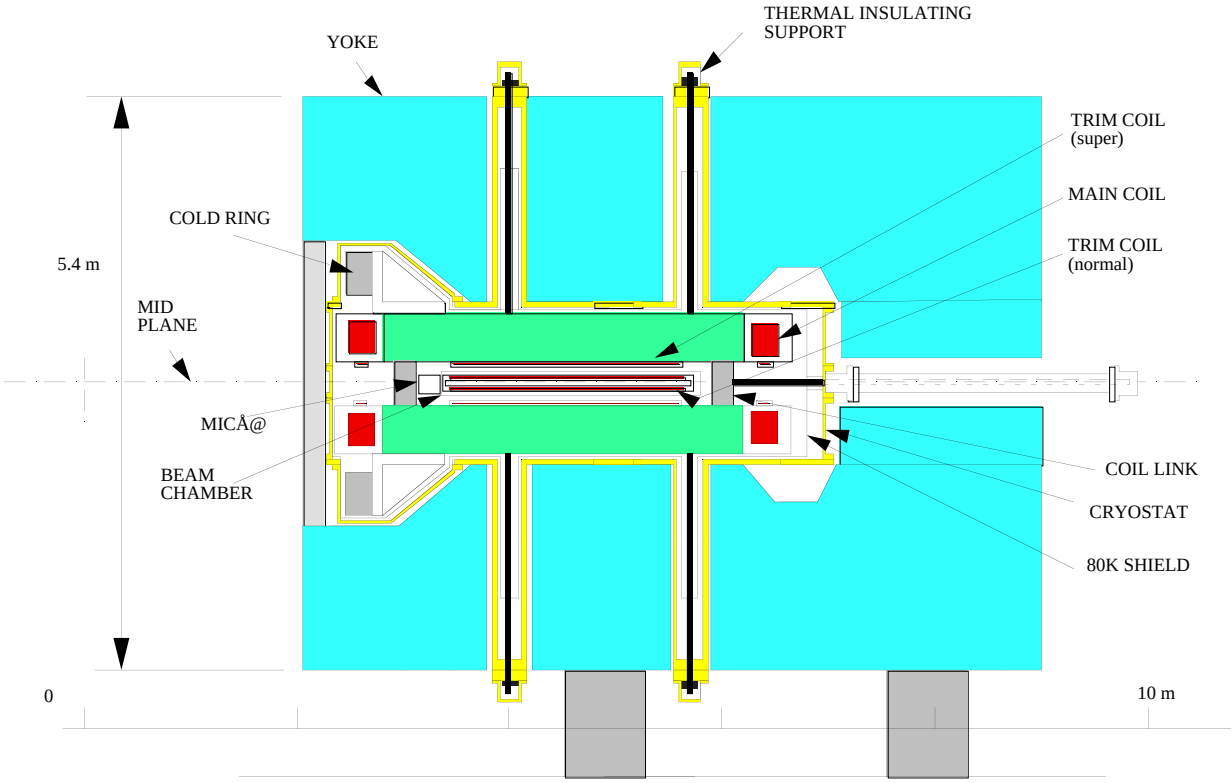

Fig. 1. Construction of superconducting sector magnet.

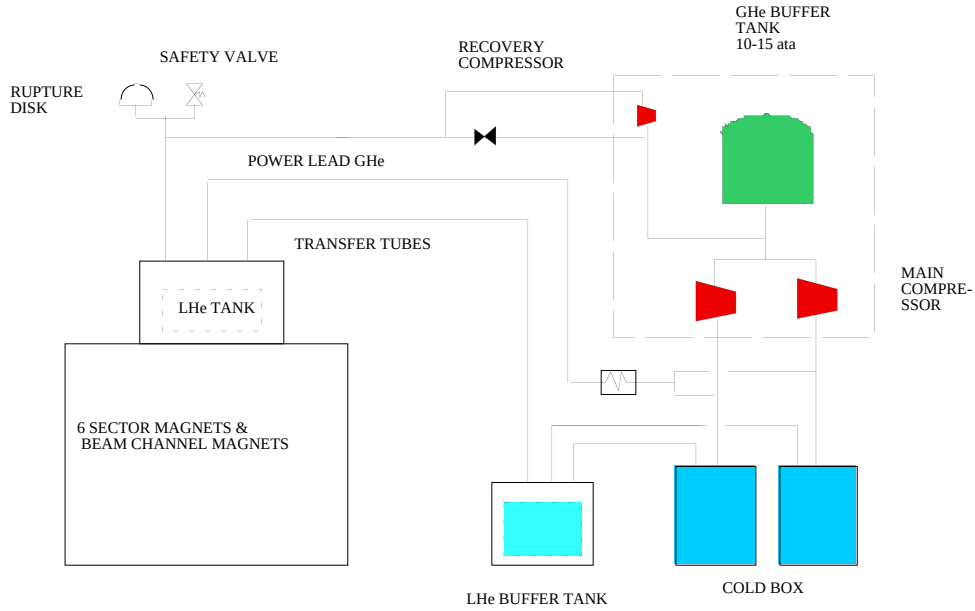

Fig. 2. Cooling diagram for 6 secter magnets and beam channel magnets