DESIGN AND CONSTRUCTION OF THE SUPERCONDUCTING BENDING MAGNET FOR THE INJECTION SYSTEM OF THE RIKEN SRC

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Abstract

A K2500 superconducting ring cyclotron with 6-sectors is being constructed at RIKEN as an energy booster of the existing K540 ring cyclotron. The bending magnet for beam injection should be superconducting. Required fields are about 4 T and curvature of the coils is about 1.2 m. We developed test coils for the bending magnet. Their results are very promising for the real bending magnet. In the paper the results of the test coils and the design of the real bending magnets are described.

1 INTRODUCTION

A K2500 superconducting ring cyclotron (SRC) will be installed as a primary accelerator of the Radioactive Isotope Beam Factory (RIBF) [1]. Its maximum bending power is 7.94 Tm and the extraction energies are 400 MeV/nucleon for light ions such as carbon and 150 MeV/nucleon for heavy ions such as uranium with an intensity of 1pμA (0.62 x 10^{13} ion/s). The design of the SRC was finalized to start the real production. Figure 1 shows a schematic layout of the SRC. The SRC consists of six sector magnets [2], four acceleration resonators and injection and extraction elements [3] and so on. The remarkable point is that iron plates of about 0.8 m thickness cover the valley regions for additional magnetic and radiation shielding. They suppress the leakage field from the sector magnets, decreasing magnetic motive forces for the maximum bending power. This makes critical parts of the SRC easier to design and produce. A superconducting bending magnet (SBM), which is one of the key elements in the SRC, can also enjoy the benefits of the additional shield. Iron can be used for the return yoke of the SBM, while iron placed in the center region does not work, due to saturation, without the additional shield. An iron-shielded magnet doesn't need as large a magnetic motive force and has a simple coil structure, compared to the iron-free magnet with an active-shield coil proposed previously. In this paper the design and R&D work of the SBM will be described.

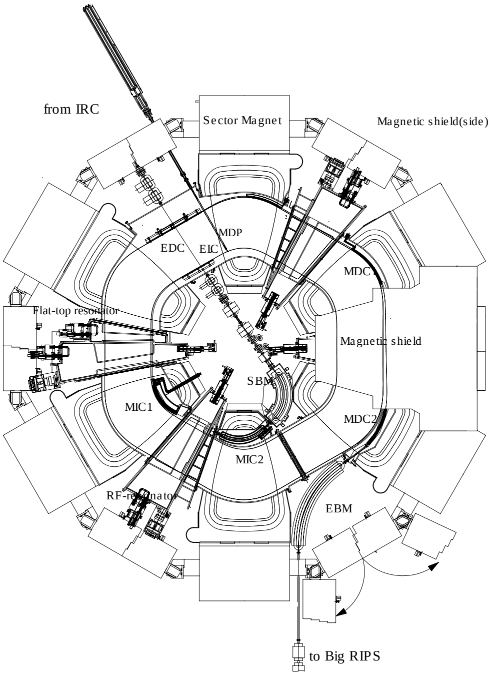

Figure 1: A schematic layout of the SRC.

2 DESIGN OF THE SBM

The main parameters of the SBM are listed in Table 1. It needs to generate a magnetic field of about 4 T along the beam trajectory which has a curvature of about 1.2 m. Figure 2 shows a proposed cross section and plan view of the SBM. The two coils, the iron poles and the yokes generate the required fields. Flat coils are adopted since they can be wound and supported easily. Iron poles are used for the mandrel of the coil windings. The yoke is divided into two parts: cold yoke and warm yoke. The cold yoke, which about half of the flux passes through, is H-type. This configuration makes shifting forces and

Table 1: Main parameters of the SBM

Item	Value
Type	Flat coil, Iron pole Iron Yoke (Cold and Warm)
Required field	4.0 T
Maximum field in the coil	4.5 T
Stored Energy	0.56 MJ
Homogeneity	few x 10^{-3}
Beam bore	40 (H) x 30 (V) mm^2
Radius	1208.4 mm (Room temperature)
Angle	75.72 degree
Coil cross section	55 x 58 mm^2

CP600, *Cyclotrons and Their Applications 2001, Sixteenth International Conference,* edited by F. Marti

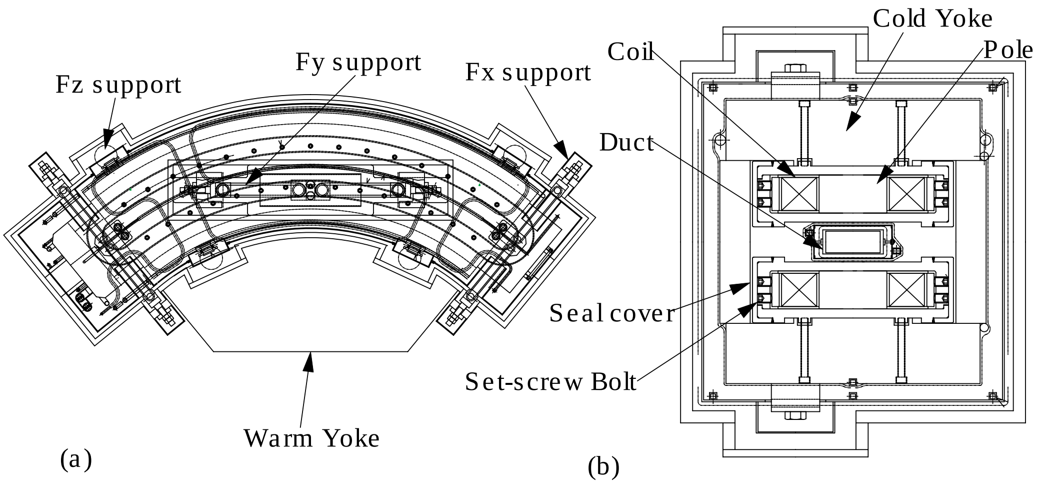

Figure 2: (a) Plane view of the SBM and (b) cross sectional view of the inside of the cryostat.

unbalanced forces on the cold mass small, while the weight of the cold mass is not too large (about 3 ton). C-type is adopted for the warm yoke because the available space for the warm yoke in the side of the sector magnet is very narrow as shown in Figure 1. A warm duct is installed for the ion beams. Iron shims and water-cooled baffle slits are attached to the duct.

Two-dimensional analysis was carried out to optimize the geometry of the coils, yokes and iron shims. The overall current density is about 150 A/mm^2 to achieve the required field. The value of current density is selected from the experience of the test coil described in the next chapter. Magnetic forces on the cold mass were calculated for the mechanical designs. The geometry of the yokes is optimized so that shifting forces and unbalanced forces on the cold mass are minimized. Three-dimensional field analysis was carried out to study the maximum fields at the coil end and the effective field lengths. Further field analyses including the six sector magnets are in progress to study coupling of the field of the SBM and the sector magnets. Preliminary results show small degradation of the field of the SBM compared to excitation of the SBM alone.

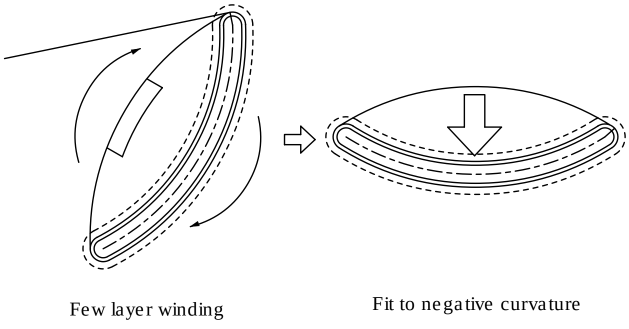

Figure 3: Concept of the winding.

Rectangular monolithic NbTi wire of 0.8mm x 2.4mm in size was adopted so as to be wound well-aligned. The conductor was coated with polyimide 50μm in thickness for electrical insulation. The operation point is less than 30% of the critical current. Coil winding is one of the key issues for the SBM production because the coils of the SBM have negative curvature, which can not be wound with any tension. The winding method shown in Figure 4 was adopted. In the first step the coil is wound with a tension in a shape which has no negative curvature. After winding of a few layers, the layers are pushed to the mandrel to make the proper shape of the coil. This method was successfully applied to the test coil production described in the next chapter. After completion of the winding, the coil is impregnated in the vacuum vessel. Figure 2 shows the cross section of the coil casing. The radial and vertical pre-compression required to keep the coil compression when the magnet is excited is provided by set-screw bolts and vertical bolts, respectively. This support structure was successfully applied to the test coil. Iron, which shrinks less from 300 K to 4.5 K than stainless steel, will be used for the inner mandrel of the center coil to decrease the degradation of the stress of the coil. The coil casing is partially covered by the seal covers for He tightness. The two coil casings are attached to the cold yoke.

The cold mass of the SBM is installed in the vacuum vessel made of structural iron of 20 mm thickness. It works as a part of the yoke which makes shifting forces and unbalanced forces small. The duct for the beam bore is connected to the vessel at its ends. The cold mass was supported by three types of thermal insulating supports from room temperature as shown in Figure 2. They are designed to support the cold mass stably against the shifting and unbalanced force as well as against big earthquakes (1 g and 0.5 g in the horizontal and vertical direction, respectively).

Total heat leaks to the cryostat are estimated to be about 56 W at 80 K, about 15 W at 4.5 K and 1.7 l/h for power lead cooling without beam loss of the accelerated ions.

A quench protection system is installed to dump the current safely. A dump resistance of 2.5 Ω is connected in parallel to the coil. Maximum temperature in the coil is estimated to be about 270 K from the hot spot model and maximum voltage on the coil is about 450 V because the resistor is terminated to ground in the middle of the resistor.

3 TEST COIL

Test coils were fabricated and tested before the design of the real SBM. The main parameters are listed in Table 2. Two types of structures were tested: one has vertical channels by two layers (Coil A) and another has no vertical channels (Coil B). Their winding method, support structure and so on were designed to be as close as possible to those of the real SBM. The test coil was tested in a field of about 4T generated with a bias split coil in order to simulate the real operation.

Figure 4 shows results of the excitations of the two coils with the real operational conditions of the SBM. They are very promising since the quenches occurred at obtained more severe condition than that of the SBM. Table 3 shows results of the transversal quench propagation velocities by measuring voltages between the taps placed in each five layers of the two coils. These results show that the normal zones in Coil B propagate in the layer direction with more than three times faster than in Coil A. From these results the coil structure of the SBM was designed based on that of Coil B.

4 CONCLUSION AND SCEDULE

The design of the superconduting bending magnets for the superconducting ring cyclotron is finalized. The results of the test coils before the real coil production are very promising. The winding of the coils for the SBM has finished. The fabrication of the SBM has started will be complete by September 2001.

REFERENCES

[1] Y. Yano et. al., “RI Beam Factory Project at RIKEN”, in this proceedings.

[2] A. Goto et. al., “Progress on the Sector Magnets for the RIKEN SRC”, in this proceedings.

[3] S. Fujishima et. al., “Design of the injection and extraction systems for the RIKEN SRC”, in this proceedings.

Table 2: Main parameters of the test coils.

Item	Coil A	Coil B	SBM
Curvature [mm]	960	960	1208
Angle [deg.]	68	68	76
Width of the inner mandrel [mm]	52	52	142
Width and height of the coil [mm^2]	23.3 x 22.5	23.4 x 22.5	58 x 55
Total turns	197	233	1317
He channel (vertical channel)	Each 2 layer	No	Each 20 layer

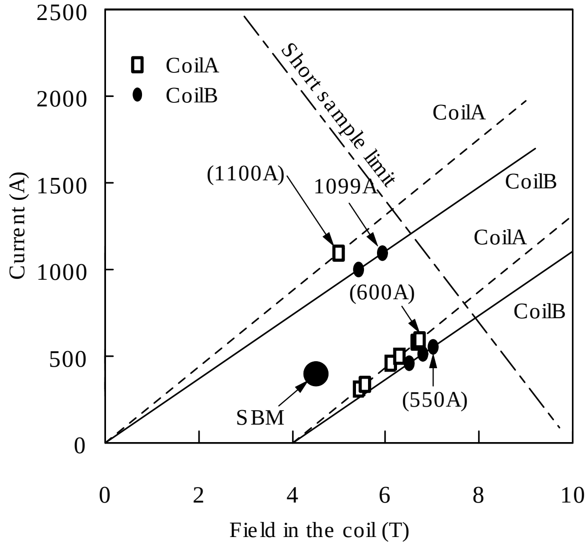

Figure 4: Quench history. White squares and black circles indicate the points where the quenches of Coil A and Coil B occurred, respectively. The currents in parentheses indicate that the excitation was ended due to the reasons other than quench.

Table 3: Results for the quench propagation velocities. I_q, B_{bias}, v_t, L indicate quench current, field of the bias coil, transversal velocity of quench propagation and the layer where the quench started.

I_q [A]	B_{bias} [T]	v_t [mm/ms]	L [layer]
Coil A			
310	4	0.014	4
335	4	0.022	1
460	4	0.038	1
503	4	0.033	16
Coil B			
460	4	0.102	1
994	0	0.190	1
1099	0	0.264	1