PA36

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

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Abstract

A conceptual design of the superconducting sector magnet for the RIKEN superconducting ring cyclotron is described. A comparison of the warm pole system with cold pole one is discussed. Magnetic forces, coil support system, coil cooling method and cryogenic system are also described.

1. Introduction

The superconducting ring cyclotron proposed for the RIKEN RI beam factory needs six units of superconducting sector magnets, each of which must generate the maximum magnetic field strength of 4 T in the beam orbital area. We use superconducting coils for the sector magnet to obtain a compactness in size and to save electric power and cooling water. The yoke and pole made of magnetic iron are arranged in the sector magnet to reduce the ampere turns of the superconducting coils and to minimize the leakage magnetic flux.

2. Structure of Superconducting Sector Magnet

Figure 1 shows an overview of the sector magnet. A cryostat is not drawn in this figure. The main components of the magnetic elements are superconducting 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. We have studied two ways of arrangements for the pole. One is a warm pole system and the other a cold pole one. Figure 2 shows the both systems and a cryostat. As for the warm pole system, the poles are directly connected to the yoke in room temperature region, and thus the cold mass at 4.5 K consists of superconducting coils and coil vessels. As for the cold pole system, the main superconducting coil is wound around the pole directly, so the cold mass consists of superconducting coils, poles and coil vessels. From points of view the mechanical rigidity and magnetic force, we have decided to use the cold pole system. However, a serious problem on the cold pole system is the difference of thermal contraction between the pole and the coil vessel during the cooldown of the cold mass from 300 K to 4.5 K. We are currently investigating this problem.

3. Magnetic Field and Forces

A three dimensional display of the magnetic field on the median plane calculated using the OPERA (TOSCA) code is shown in Fig.3. Figure 4 shows the comparison of expanding forces on the straight section of the main coil between for the warm pole system and the cold pole one. It is clear the force in the cold pole system can be reduced by one-third of that in the warm pole system. This effect is due to the short distance between the main coil and the pole in the cold pole system. Figure 5 shows the changing of the maximum magnetic field (at a radius of 6 m on the median plane) and the magnetic forces Fx,Fz in the cold mass (consists of main coils and cold poles), as a function of the ampere turns of two (a pair of) main coils . The magnetic force Fz in the vertical direction is supported with two coil links which are arranged between the upper cold mass and lower one. The force of 300 tons maximum causes a mechanical deflection of about 4 mm maximum of the cold mass. The magnetic force Fx in the radial direction is generated with a configuration of the six sector magnets . Each cold mass is pushed toward outer radius by the forces from sector magnets at both-side. The maximum force of Fx is estimated to reach about 500 tons per each magnet. It is very difficult to support this force by thermal insulating supports which locate in between the cold mass and the vacuum vessel. To support such a large Fx, we are investigating a cold ring of 2.6 m in diameter and 200 mm in thickness which connects the six cold masses in the central region of the ring cyclotron.

4. Superconducting Coils

The main superconducting coil has a triangle shape with two long straight sections of about 4 m length. This force is supported by the coil vessel and the cold pole. It is very hard, particularly for the coil in non-circular shape, to prevent the coil's wire movement that causes a coil quench. However, we should avoid the coil quench,because the total magnetic energy stored in six magnets reaches as much as 300 MJ. Quench-free is indispensable for maintain a reliable long-time operation for the cyclotron. Taking the above matter into account, we apply fully cryogenic-stable cooling for both the main coil and the trim coil adopting a method of conservative liquid-helium bath cooling. The operation currents of the main coil and trim coil are roughly set to be 5000 A and 500 A, respectively. In order to maintain the cryogenic stability, the average current densities of them should be less than 40 A/mm^2 and 50 A/mm^2, respectively.

5. Cryogenic System

The total heat leak of six magnets is roughly estimated to be 500 W at 4.5 K. A helium refrigerator having a capacity of 1 kW at 4.5 K stage will be used for six sector magnets and the beam injection & extraction channels. Weight of the total cold mass of six magnets is about 360 tons. It will take almost one month for the cooldown of the cold mass from room temperature to 4.5 K by the helium refrigerator.

6. Conclusion

Conceptual design of the superconducting sector magnet for the RIKEN superconducting ring cyclotron has been carried out. The arrangement of the coil and pole has been studied, and we have decided to adopt the cold pole system in order to support and reduce the magnetic forces in the coil. We are planing to construct a model of the superconducting sector magnet to confirm our design.

References

1. Y.Yano, "RIKEN RI-Beam Factory Project", This symposium.
2. T.Mitsumoto et al., "Design Study of Superconducting Sector Magnet for the RIKEN Superconducting Ring Cyclotron (I)", This symposium.

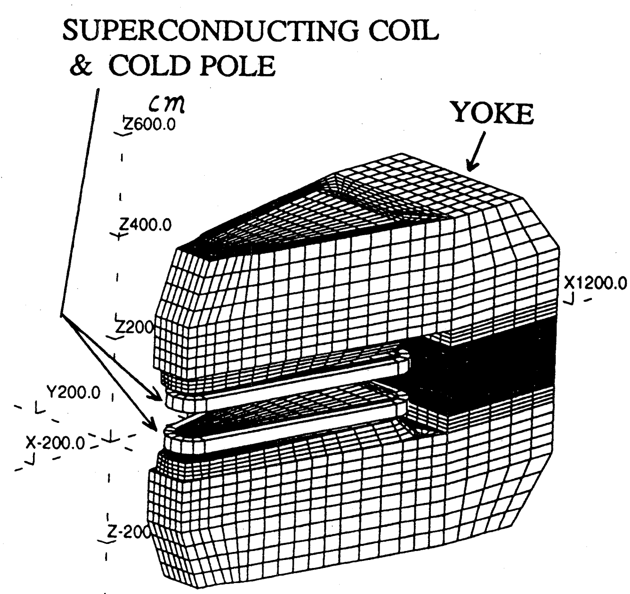

Fig.1 Overview of Superconducting Sector Magnet (for three dimensional magnetic field calculation)

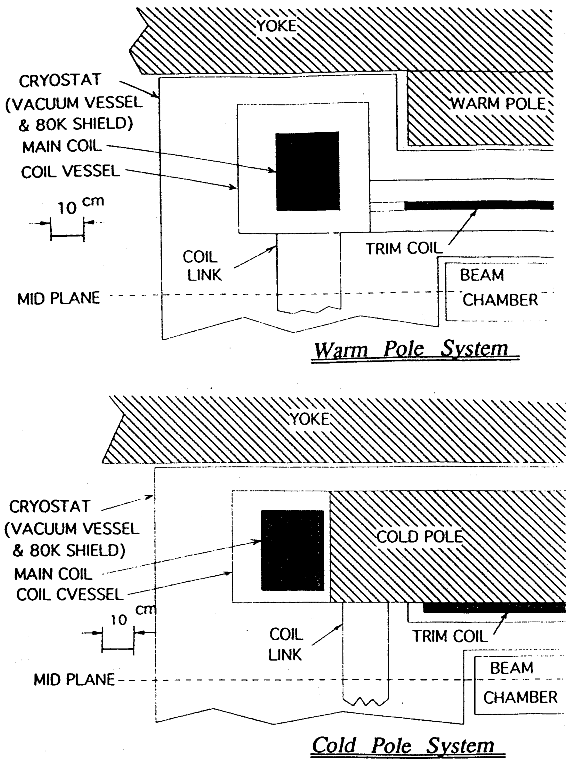

Fig.2 Comparison of Pole Arrangements

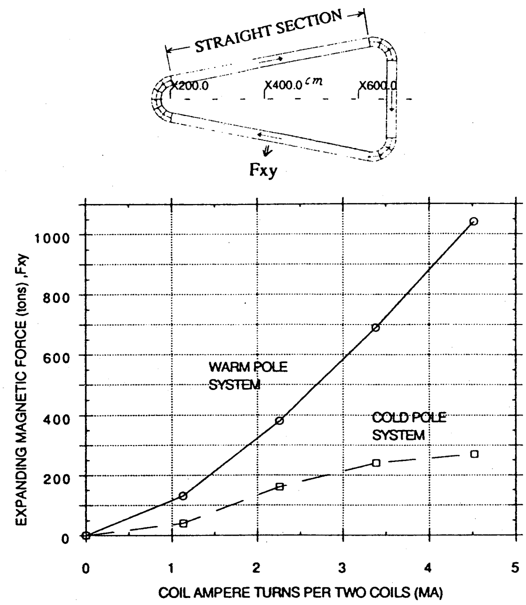

Fig.4 Comparison of Expanding Magneic Forces in Coil Straight Section

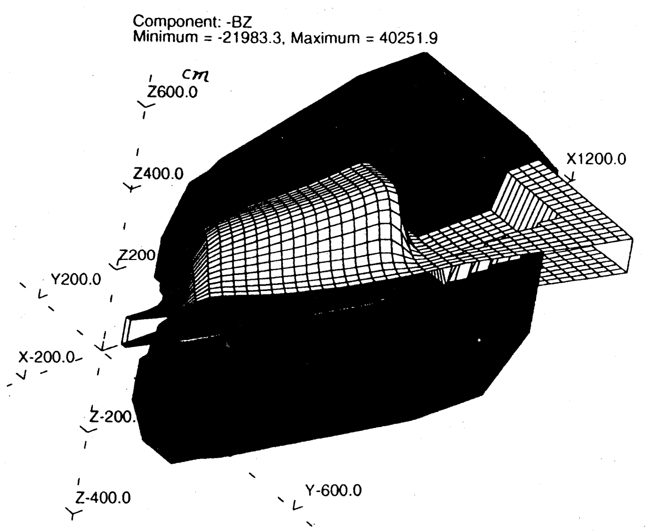

Fig.3 Three Dimensional Distribution of Magnetic Field in Mid Plane

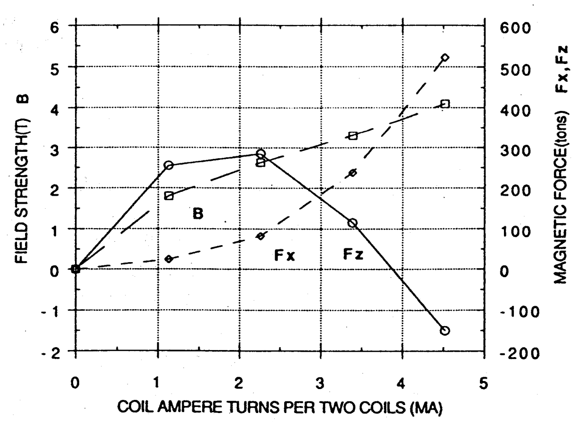

Fig. 5 Field Strength & Magnetic Forces