Construction of the RIKEN Superconducting Ring Cyclotron

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Abstract

A K2500-MeV superconducting ring cyclotron with six sectors is being constructed at RIKEN as the second stage of two boosters of the existing K540-MeV ring cyclotron. Design of components of the superconducting ring cyclotron and status of a full-scaled prototype of the sector magnet are described.

1 Introduction

Construction of the two booster ring cyclotrons of the existing K540-MeV ring cyclotron (RRC) has started since FY 1998 for the RIKEN RI beam factory, which is aimed at providing RI beams covering the whole atomic-mass range with very high intensity. The boosters consist of a K980-MeV room-temperature ring cyclotron with four sectors (IRC) [1] and a K2500-MeV superconducting ring cyclotron with six sectors (SRC). They will allow us to boost ion beams from the RRC up to 400 MeV/nucleon for light heavy ions like carbon and over 100 MeV/nucleon for very heavy ions like uranium.

Since last meeting we have newly studied and redesigned some components of the SRC, and have done some tests and R&D's in constructing a full-scaled prototype sector magnet. In this paper are described such components and status of the prototype sector magnet.

2 Description of the SRC

2.1 General Features

Fig. 1 shows a schematic layout of the SRC. The SRC consists mainly of six sector magnets with an angle of 25 deg, four acceleration rf resonators, a flat-top resonator and injection and extraction systems. The SRC has been redesigned to have four acceleration rf resonators from three in previous design [2]. This decision was made to obtain a better beam extraction efficiency by enlarging the turn separation, despite that design of the components such as injection and extraction elements, a flattop resonator and beam diagnostic devices becomes tight due to lack of available space. These components have been redesigned accordingly. A single turn extraction is assured for the SRC by employing four resonators; the minimum last-turn separation increases from 8 mm to 11 mm. Table 1 shows characteristic parameters of the SRC.

2.2 Sector magnet

The remarkable features of the sector magnet are: 1) it adopts a cold-pole arrangement and 2) the main coil and trim coil are designed to be cryogenically stable.

Some of the designs of the sector magnet have been changed since last meeting. One of the big changes is that the "hooks" anchoring the main coil vessel to the pole has been designed to be replaced by two connecting plates covering the surfaces of the pole (see section 3). The pole gap has been widened from 380 mm to 400 mm in order to make more space for the magnetic inflection channel (MIC2). The vertical, radial and azimuthal thermal-insulation supports have been designed to withstand not only the magnetic forces but also an acceleration of 1 G (in the horizontal direction) and 0.5 G (in the vertical direction) in an earthquake. The other fundamental parameters have

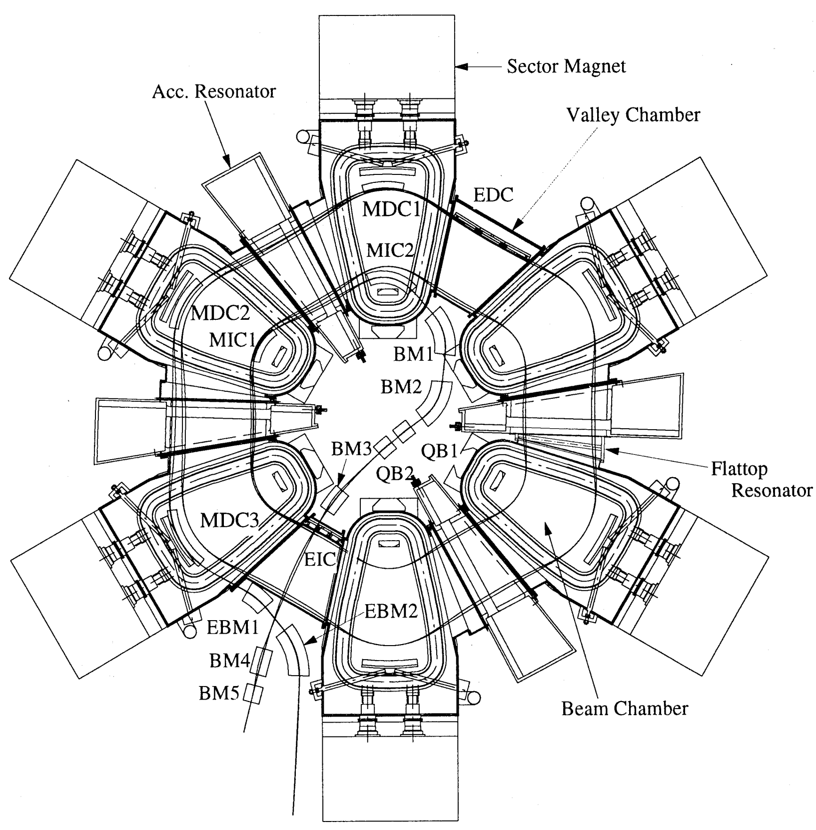

Fig.1 Layout of the IRC.

Table 1
Characteristic parameters of the SRC.

K-value	2,500 MeV
No. of sector magnets	6
Sector angle	25 deg
Mean injection radius	3.56 m
Mean extraction radius	5.36 m
Maximum magnetic field	4.5 T
Maximum stored energy	390 MJ
Total weigh of magnets	5,000 ton
No. of rf resonators	4+1
Frequency	18 – 38 MHz
Beam energy	
Light ions (m/q=2)	400 MeV/u
Kr ion	300 MeV/u
U ion	150 MeV/u

been fixed. The sector angle is 25 degrees. The sector magnet is 7.8 m in length and 6.0 m in height. The maximum currents required for the main coil and trim coil are 5,000 A and 500 A, respectively. The maximum magneto-motive force per sector magnet is 6 MA.

2.3 Injection and extraction

The injection and extraction systems have been redesigned as shown in Fig.1 according to the employment of the four acceleration rf resonators [3]. The number of magnetic inflection channels has been reduced from three to two (MIC1 and MIC2). The injection beam is transported through the hole of the electrostatic inflection channel (EIC) as well as the gap between the extraction bending magnets (EBM1 and EBM2). The bending magnets (BM1, BM2, QB1 and QB2) and the magnetic inflection channel (MIC2) are designed to produce a gradient field superimposed on a dipole field. This allows us to match the phase profile of the injected beam to the eigen-ellipse of the SRC keeping the beam size in the injection elements small enough.

All the bending magnets and magnetic channels shown in Fig. 1 except for the MIC1 and the MDC1-3 are superconducting. Among them the MIC2 is particularly difficult to design and make because of the following characteristics: 1) it has negative-curvature coils, 2) the required field in the coils is as high as 6 T and 3) the space for the installation is limited. Therefore, we are making a prototype of the MIC2, which will be tested in a prototype sector magnet. The cold mass of the MIC2 is designed to be installed in a space separated from the cryostat of the sector magnet so that the MIC2 can be maintained independently.

2.4 RF

The rf resonators have been designed using a three-dimensional computer program MAFIA [4]. The four acceleration resonators are of a single-gap type with a pair of rotatory tuning panels. Their resonant frequency can cover the range from 18 MHz to 38 MHz. The necessary maximum power is estimated to be 115 kW/resonator for a gap voltage of 600 kV (at 38 MHz), which is large enough to achieve a single-turn extraction for 400 MeV/nucleon light heavy ions. The third-harmonic flat-top resonator is of a single-gap type with a pair of movable shorting plates. It is placed in a very small space between the acceleration resonator and the sector magnet as shown in Fig. 1.

A 1/10-scaled model of the acceleration resonator was made with wood boards covered with an aluminum foil of 15 μm in thickness. The resonant frequencies agreed well with the MAFIA calculation within the accuracy of a few percent. A 1/5-scaleed model of the resonator for the IRC, which is quite similar to that of the SRC, was also made with copper plates and tested [5]. The measured resonant frequencies agreed well the calculation; the measured Q-values were 60–70 % of the calculated values. The size of the inductive coupler for the real resonator was determined using this model.

2.5 Vacuum

In order to achieve the goal of 99 % beam transmission in the SRC, the pressure of the beam chamber is required to be below 1×10^{-5} Pa. The designed pumping system consists of a roughing system, a high-vacuum system, an ultra-high-vacuum system and a differential pumping system [6]. The differential pumping system is used for the evacuation of the rf resonators, which have a structure of duplicated walls: thin copper plates are attached to the inside surface of the thick stainless steel wall of the chamber [7]. Eighteen cryopumps with a total pumping speed of 170 m^3/s are planned to use as a main pumping. Total effective pumping speed at the beam passage is estimated to be about 75 m^3/s; the pumping-down time is to be about a few hundreds hours.

A cold-cathode gauge will be used during the SRC operation, because a hot-ion gauge is of no practical use due to the large leakage magnetic field from the sector magnet. From the test of cold-cathode gauges in a magnetic field, it was found that a gauge without a permanent magnet would be better to use [8].

2.6 Magnetic shield

The leakage fields from the SRC have to be shielded outside the cyclotron room. We have studied two methods: one is to cover the whole room with iron plates and the other to place large Helmholtz coils around the SRC. The shape of iron shield assumed for the calculation is a cylinder whose diameter, height and thickness are 26 m, 12,and 16 cm, respectively. The total weight was calculated to be about 2,600 tons. On the other hand, the diameter of the Helmholtz coils studied is 24 m and the distance between the two coils is 5.2 m. The magneto-motive force

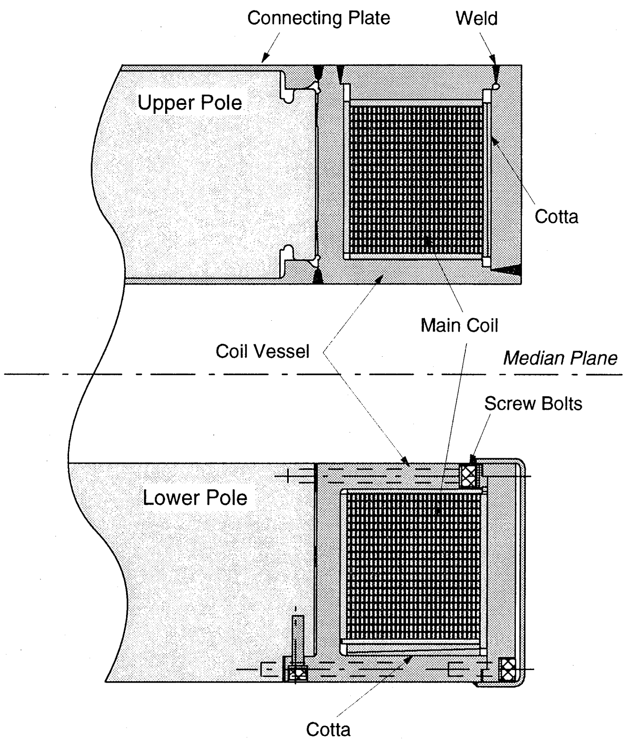

Fig. 2 Cross-sectional view of the sector magnet of the SRC.

was calculated to be 360 kA. Cryogenic design of the coils is being made in detail.

3 Prototype of the sector magnet

We have constructed a full-scaled prototype sector magnet of the SRC to verify particularly the mechanical design of magnet and the cryogenic design of the main and trim coils. Two kinds of schemes are adopted in the model as shown in Fig. 2. In the scheme shown in the upper figure, a sort of connecting plate is used to fix the coil vessel to the pole. The coil vessel and the connecting plate are assembled by weld. In the scheme shown in the lower figure, screws are used to fix the coil vessel to the pole as well as assemble the coil vessel. A photograph of the main coil vessel where main coils are wound is shown in Fig. 3.

We have made some tests and R&D's related to the prototype sector magnet [9]:

1) Measurement of mechanical properties of the pole material at 77 K and 4.2 K
2) Measurement of heat transfer from the superconductors to liquid helium
3) Measurement of mechanical properties of the superconductors such as tensile strength, stress-strain hysterisis, fatigue and stress-creep characteristics at room temperature and 77 K
4) Measurement of fatigue characteristics of the structure of the cold pole and the main coil vessel at 77 K

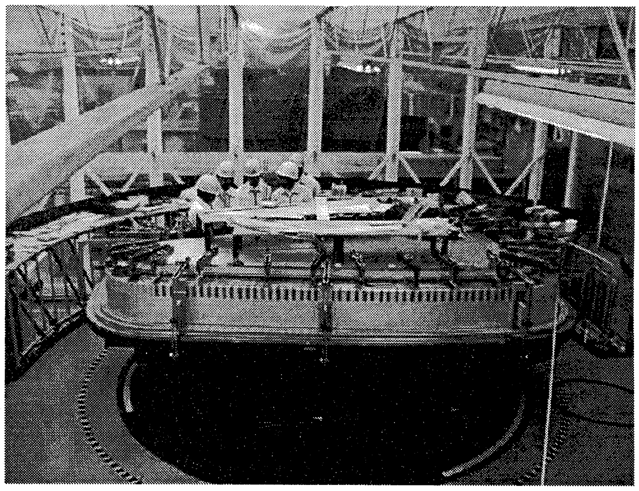

Fig. 3 Photograph of the main coil winding.

5) Test on the cryogenic-stability using a small model coil wound with the main/trim coil superconductors
6) Measurement of compression stiffness of the main coils
7) Fabrication of each model of main coil assembly in the straight section for the two assembling scheme
8) Measurement of the unbalanced magnetic forces using three sets of 1/6-scaled sector magnets with normal conducting coils operated in a pulsed mode.

Construction of the whole system is scheduled to be completed in the spring of 2000.

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