Status of the RIKEN SRC

H. Okuno, J. Ohnishi, N. Fukunishi, T. Mitsumoto, S. Fujishima, T. Tominaka, N. Sakamoto, O. Kamigaito, M. Fujimaki, K. Ikegami, Y. Miyazawa, M. KaseA. Goto and Y. Yano, RIKEN, Wako, Saitama 351-0198, Japan Japan

Abstract

The RIKEN SRC (superconducting ring cyclotron) is under construction. Significant changes have been made in the last stage of the design works. In the new design the cyclotron is almost completely covered with soft-iron slabs of about 1 m in thickness, which give additional magnetic and radiation shield. They suppress the stray field from the sector magnets, decreasing magnetic motive forces for the maximum bending power. This makes all critical parts of the SRC more feasible and stable to work. The new design and status of the construction are described in this paper.

1 INTRODUCTION

A K2500 superconducting ring cyclotron with 6-sectors (SRC) is being constructed at RIKEN as the final energy booster of the new cyclotron cascade in the RI beam factory (RIBF) [1]. The maximum magnetic rigidity of extracted beams is 8 Tm which exceeds that of 350 MeV/nucleon U^{88+} beam. The mean extraction radius is 5.36 m and the harmonic number is 6.

Significant changes have been made in the last stage of the design works. In the new design, the cyclotron is almost completely covered with soft-iron slabs of about 1 m in thickness, except in the central region as shown in Fig. 1. The "iron cover" yields the following good results:

(1) The SRC can be self-radiation-shielding.

(2) The stray field in the valley is reduced from 0.5 T to 0.1 T at the maximum. The sector field needed to bend, for example, U^{58+} 150 MeV/nucleon is accordingly reduced from 4.3 T to 3.7 T because of this reduction of negative stray field, with the K-value of the SRC being kept at 2,500 MeV. According to this lower flutter, we relocate the operating domain of the vertical betatron frequencies from the values between 1.0-1.5 to those between 0.5-1.0. The decrease of the vertical betatron frequencies causes an increase in the vertical beam size by a factor of about 1.4, but this presents no problem because of sufficient acceptance of the injection and extraction elements. This decrease also makes the tolerances of the main and trim coils and poles tighter, but they are still tolerable. According to the reduction of the maximum sector field, the maximum magneto-motive force required is also reduced from 5.4 MA/sector to about 3.8 MA/sector. The maximum stored energy and the electromagnetic forces exerted on the main coil are greatly reduced from 390 MJ to 235 MJ and from 400 Ton/m to 260 Ton/m, respectively. This reduction of forces allows us to adopt a warm-pole scheme; there is now no concern about brittleness of the iron pole at low temperature. The small stray field in the valley allows us to use cryopumps, motors, control devices, and so on in a safe situation.

(3) Superconducting magnetic channels for beam injection and extraction are unnecessary. Now all the injection and extraction magnetic channels inside gap of the sector magnets are normal with the moderate power consumption, and their structures are similar to those for the RRC and the IRC[2].

(4) The shift of the injection and extraction trajectory depending on the negative stray field strength is greatly reduced.

(5) The stray field outside the SRC is reduced to about 200 gauss at the maximum near the yoke and the vertical side shield-wall. We need neither the active magnetic shielding which was adopted in the old design nor the thick iron plates enclosing the huge SRC vault. We place the rf oscillators near the SRC like they are for the RRC and the IRC. The SRC vault is now very safe for those working at the site even inside the cyclotron.

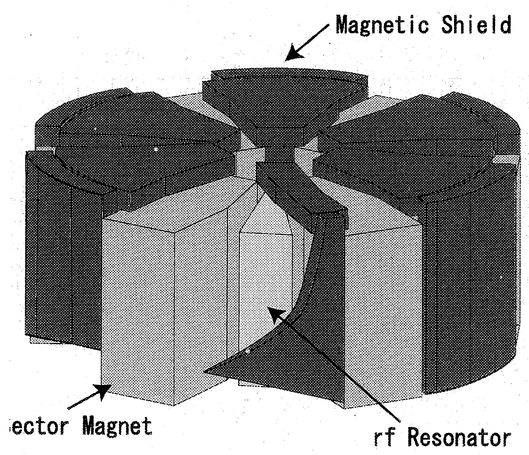

Fig. 1: A schematic illustration of the SRC.

Okuno@postman.riken.go.jp

2 DESIGN OF THE SRC

Number of sector magnets	6
Sector angle	25 degree
Gap width	640 mm
Gap width for the beam	90 mm
Dimension	
Diameter	18.8 m
Height	7.9 m
Mean injection radius	3.56 m
Mean extraction radius	5.36 m
Orbital freauency	3 – 6.3 MHz
Harmonic number	6
Betatron frequency	0.5-1.0 (vertical) 1.1-1.5 (Horizontal)
Total weight	7800 ton
Sector Magnet	
Maximum magnetic field	3.8 T
Maximum stored energy	235 MJ/sector (max.)
Accuracy of isochornism	1×10^{-4}
Current Stability	5×10^{-6}
Main coil	
Magneticmotive force	3.96 MA/sector (max.)
Nominal current	5000 A
Superconducting trim coils	
Number of the sets	4 set x 2(up/down)/sector
Maximum current	3000 A
Normal trim coils	
Number of the sets	22 set x 2(up/down)/sector
Nominal current	600 A
RF system	
Number of resonator	4 (Accel.), 1(Flattop)
Gap	Single gap
Turn seperation	> 4mm (w/o precession)
RF range for acceleration	18 – 40.5 MHz
Tuner	Flapping panel
Maximum RF voltage	600 kV/gap (Accel.)
Maximum RF power	150 kW/res. (Accel.)
Injection and extraction sytem	
Injection elements	1 EIC, 2 MICs, 1 SBM
Extraction elements	1 EDC, 3 MDCs, 1 EBM
Evacuation system	
Main evacuation system	
Cryopump	14(10000 l/s), 2(5000 l/s)
Turbo molecular pump	4(5500 l/s)
Final pressure	$< 1 \times 10^{-6}$ Pa
Beam Diagonics	
Elements	1 MDP, 2 ERPs, 20 PP and Buffle slits
Magnetic Shield	
Weight	3000 Ton
He cooling system	
Type of refrigerator	Claude cycle
Cooling capacity	800 W @4.5 K + 4000 W @ 70 K+ 110 l/h (P.L. cooling)
Control dewar	2100 litter

Table 1: Main parameters of the SRC. See the text and Fig. 1 for the meaning of the symbols in it.

A layout and main parameters of the SRC is shown in Fig. 1 and Table 1, respectively. The SRC consists mainly of six sector magnets, four main rf resonators, a flattop rf resonator, injection and extraction elements, magnetic shield. Evacuation system, beam diagonics and He cooling system are also installed for each purpose.

The sector magnet is 7.2 m in length and 6 m in height. The weight is about 800 Ton per each. The sector angle is 25 deg. The maximum sector field is 3.8 T, which is required to accelerate 350 MeV/nucleon U^{88+} ions. Main components of the sector magnet are: a pair of superconducting main coils, four sets of superconducting trim coils, their cryostat, thermal insulation support links, twenty-two pairs of normal conducting trim coils, warm-poles and a yoke. Our goal of accuracy of the isochronous field is less than 1×10^{-4}. The details are described in [3,4].

The elements listed in Table 1 are installed for beam injection and extraction. The structures of electrostatic and magnetic channels (EIC, EDC, MICs, and MDCs) are similar to those of RRC and IRC. Analysis of their electric and magnetic properties, however, was carefully made because their required fields are much higher than those of RRC and IRC. The superconducting bending magnet (SBM) for beam injection is required to generate about 3.8 T along the trajectories. The SBM are under fabrication after the some test coils [3]. The extraction bending magnet generate 2.04 T in the long trajectory of 3.8 m. Its structure was designed so that horizontal and vertical steerer were imbedded and profile monitor can be installed at the middle of the trajectory in order to extract the beams with high efficiency [5].

RF system is designed to generate energy gain of about 2.4 MV/turn, which give as large turn separations as more

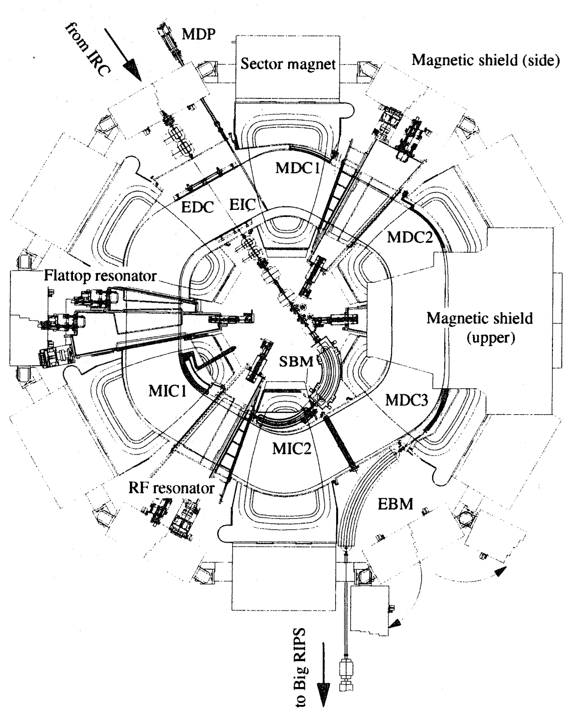

Fig. 2: Plan view of the SRC.

than 12 mm for beam extraction without beam losses, using the *off-centering acceleration technique* which is routinely used for the RRC operation. A single-gap-type resonator whose structure basically the same as that of the RCNP ring cylotron and the IRC was adopted for the acceleration resonator[6]. Canning of the resonators is undergoing now.

There are three kinds of vacuum: vacuum for beam, thermal insulating vacuum for the superconducting coils, and sub-vacuum in the resonator for decrease the outgasing into the vacuum for beam. The chamber which separate the beam vacuum from the thermal insulating vacuum in the sector magnet was designed to be enough rigid to open the beam chamber keeping the thermal insulating vacuum. Expansion seals are adopted for the connections with twelve chambers where the beams pass. A high vacuum of less than 1x 10^{-6} Pa is required for as high transmission as more than 99 % during acceleration.

One differential probe (MDP), twenty phase probes (PP) and radial probes in extraction regions (ERP) are installed for beam-monitoring. Their detailed designs are in progress based on the experiences in RRC operation. Buffle slits for beam protection and monitoring are installed at the entrances of most elements for beam injection and extraction. The entrances of the MIC2 and MDC3 is difficult to install the slits due to the narrow available spaces. The designs of their structures are in progress, taking how to replace them in cases of any troubles into account.

Some of the iron slabs of the magnetic shield are bridged on the top and bottom of the valley regions between the sector magnets. The others are placed vertically between these top and bottom slabs so as to cover the space between the back yokes of the neighboring sector magnets. Cross-sectional and plan views of the magnetic shield are shown in Fig. 9. The total weight of these six falling-U-shaped structures is about 3,000. The vertical outside slabs are assembled to form a double-leafed hinged door to be opened when the maintenance is carried out for the rf resonators, vacuum pumps, and so on in the valley region. Asymmetries of the sector field due to inaccuracies of their size were studied. The study let us to make a decision to machine each slab "beautifully" because disturbances to accelerated beams are estimated to be not negligible, assuming accuracy of non-machined slabs.

The cooling system is a closed-circuit system without liquid nitrogen. It consists mainly of the six cryostats of the sector magnets, the cryostat of the injection-bending magnet, a control dewar, a refrigerator, three compressors and five buffer tanks. The control dewar of 2.5 m in diameter and 3 m in height is located on the top of the six sector magnets. The superconducting conductors of the coils are electrically connected to the power leads in the liquid helium vessel of the control dewar. The total volume of liquid helium in the main coil vessels for the six sector magnets is about 2,100 L and that in the control dewar is 2,000 L. By taking the injection bending magnet into account, the refrigerator is designed to have a capacity of 600 W at 4.5 K for the coils, 3500 W at 70 K for the thermal shields, and 4 g/s for the current leads. The total equivalent refrigeration capacity at 4.5 K is thus about 1.3 kW. The time required to cool-down the cold mass of 180 Ton in from room temperature to 4.5 K is estimated to be about 20 days.

3 CONSTRUCTION SCHEDULE

Figure 4 shows the status of the construction of the SRC vault where six bases for the sector magnets and magnetic shield has been settled. Their construction will finish until March of 2003 including installation of the infrastructures. It takes the longest time to fabricate the sector magnets. Winding of the coils will start in this autumn and all fabrications of will finish in March of 2003.

6 REFERENCES

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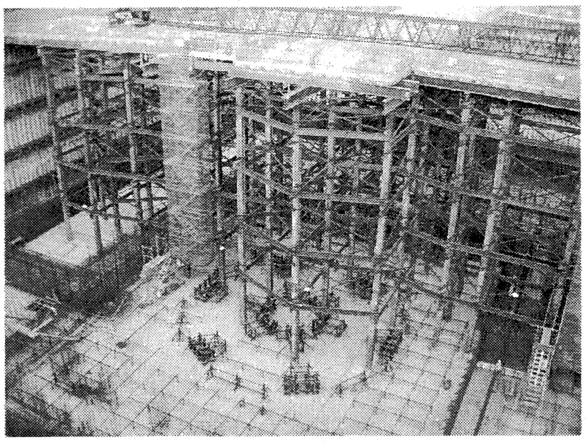

Fig. 3: Status of the construction of the SRC vaults (April 2001). The temporary structure for the building construction is also seen.