NEW 28GHZ SC-ECRIS FOR RIKEN RI BEAM FACTORY PROJECT

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Abstract

To increase the intensity of U ion beam for RIKEN RI beam factory project, we started to construct new SC-ECRIS. The main features of the ion source is as follows 1)the ion source has a large size of ECR surface 2) field gradient and surface size at ECR zone can be changed independently to study these effects on the ECR plasma. Six sets of solenoid coils and hexapole coil are used for making the magnetic field. The maximum magnetic field of RF injection side (B_{inj}), beam extraction side (B_{ext}) and radial magnetic field at the plasma chamber surface (B_{r}) are 3.8, 2.4 and 2.1T respectively. The construction began at Mitsubishi Electric Corporation in October 2007. After all the coils were wound and assembled, the excitation tests were performed in June 2008. After excitation test, we obtained the 85~90% of designed value. In the excitation test, we recognized that it is necessary to reinforce the structure at the coil ends of the hexapole. After the test, we started to modify the structure of the hexapole coil end. In September 2008, we will start the second excitation test.

INTRODUCTION

Since middle of 1990s, RIKEN has undertaken construction of new accelerator facility so-called Radio Isotope Beam Factory (RIBF) [1] and successfully produced 345MeV/u U beam (~4 nA on target) in 2007.[2] However, to meet the requirement of the RIBF (primary beam intensity of 1pμA on target), we still need to increase the beam intensity of the heavy ions. For this reason, we started to construct the new superconducting ECR ion source (SC-ECRIS) which has an operational frequency of 28 GHz.

Before construction, we intensively studied the effect of the key parameters (magnetic field, RF power, gas pressure bias disc etc) on the plasma and beam intensity for optimizing the structure of the ECRIS. During the investigation, we obtained several interesting results.[3-5] Based on these results, we designed the ion source and made a first excitation test of SC-coils.

In this paper, we report the structure, progress of the new RIKEN SC-ECRIS construction

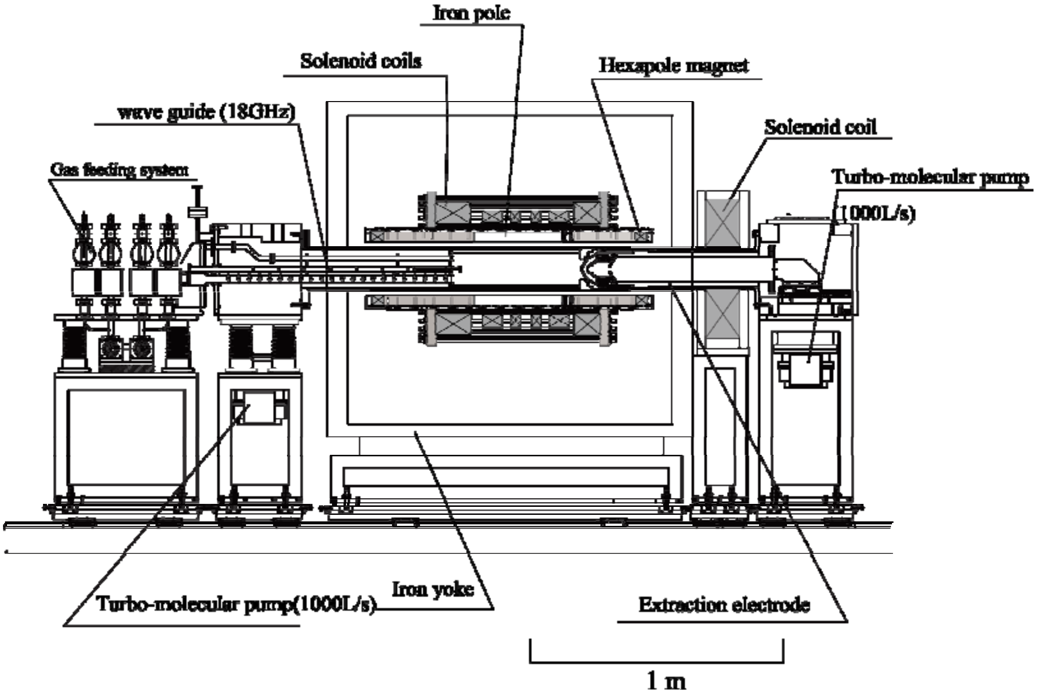

Fig.1 Schematic drawing of the RIKEN SC-ECRIS

SOURCE DESGIN

Figure 1 shows the mechanical layout of the RIKEN SC-ECRIS. As described in ref.3, we used the six solenoid coils to choose the resonance surface size and field gradient at resonance zone, independently. Using this system, we can test the effect of field gradient and zone size on the beam intensity. Figure 2 shows the ECR zone size vs. B_{min}.

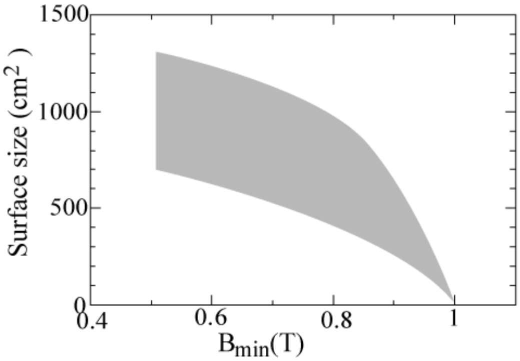

Fig.2. ECR zone size vs. B_{min}.

Superconducting coils and cryostat

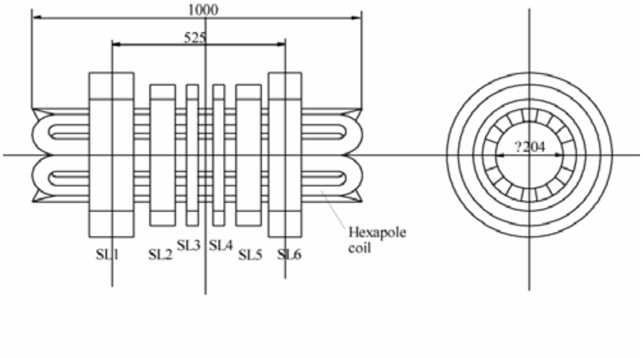

Fig.3. Schematic drawing of the superconducting coils

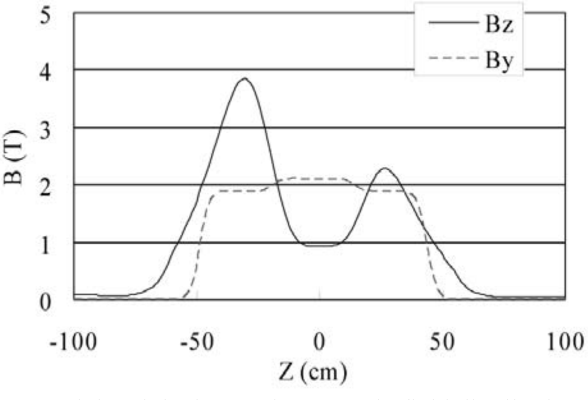

Fig.4. Axial and the hexapole magnetic field distributions along the beam axis

A schematic drawing of the superconducting coils is shown in Fig.3 [7]. Figure 4 shows the designed axial and the hexapole magnetic field distributions along the beam axis. The maximum axial magnetic fields are 3.8 T at the RF injection side (B_{inj}) and 2.2 T at the beam extraction side (B_{ext}). Inside radii of the hexapole and solenoid coils are 102 mm and 170 mm, respectively. Four coils (SL2 ~SL5) are used for making a flat magnetic field region between the mirrors. The maximum hexapole magnetic field is 2.1 T on the inner surface of the plasma chamber (r = 75 mm). The hexapole magnetic field in the central region is increased by using iron poles, which is same structure as the VENUS.[6] A NbTi-copper conductor is used for coils and these are bath-cooled in liquid helium. Parameters of the coils are shown in Table 1. A conductor with a round shape of φ1.09(a NbTi/Copper ratio of 6.5) is used for SL3 and 4. A conductor with a rectangular shape of 0.82 mm x 1.15 mm (a NbTi/copper ratio of 1.3) is used for the other solenoid coils and the hexapole. Figure 5 shows the Ic performance of the conductor with a rectangular shape and the load points for the solenoid SL1 and the hexapole. Although the maximum field on the hexapole coil windings is 7.4 T, the component perpendicular to the current direction is 6.5 T. The magnetic stored energy is 830 kJ with all coils at the design current.

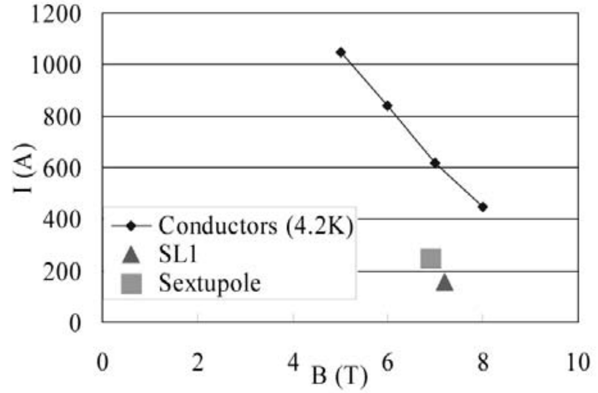

Fig.5. I_c performance of the conductor with a rectangular shape and the load points for the solenoid SL1 and the hexatupole

The longitudinal distributions of the magnetic force acting on the straight region of the hexapole coils are shown in Fig. 6. Because the expansion magnetic force in the azimuth direction is generated by their self-field as well as the radial magnetic field of the solenoids, its magnitude changes according to the longitudinal position and the polarity of the hexapole coil. It is clearly seen that the magnetic force becomes strongest in the region between the SL1 and the SL2. The six hexapole coils are assembled using titanium spacers with a triangle cross section and fixed with four layers of φ0.65 mm stainless steel wires wound with very high tension of about 580 MPa. A stainless steel disk with outer diameter of 250mm and a thickness of 30 mm are inserted between the SL1 and the SL2 to fix the hexapole coils more tightly because the magnetic force in the azimuth direction is strongest there. 3D calculations of the deformation of the coil assembly were performed with ANSYS [7]. The coils were treated as orthotropic material where the elastic coefficients are 97 GPa in the direction of conductors and 16 GPa in the orthogonal. Assuming that a shrinkage factor of the coils is 0.5% in the cooling down to the LHe temperature, the tension of the binding wire was calculated to decrease by 25% and the coils to shift inward by 0.16 mm at the maximum due to the remaining compressive force. Each of the hexapole coils was dry-wound to work for turn transitions and was vacuum impregnated with epoxy. The percolation of the epoxy into the inside of the windings was inspected to be successful by cutting a trial winding. On the other hand, each solenoid coil was wet-wound with warm epoxy and cured. Figure 7 shows the final assembly of the hexapole coils and six solenoids. The ends of the hexapole coils are fixed with a stainless steel ring to support the large radial magnetic force acting on the current return sections. The six solenoids were assembled with stainless steel spacers and tightened with sixty-four long aluminum-alloy bolts that support a repulsive force of approximately 800 kN at the maximum.

Table 1. Parameters of the superconducting coils

	SL 1	SL 2	SL 3	SL 4	SL 5	SL 6	Sextupole
Inner radius (mm)	170	175	175	175	175	170	102
Outer radius (mm)	250	220	220	220	220	250	142
Length (mm)	135	75	35	35	75	100	1073
Conductor size (mm)	0.82 x 1.15	0.82 x 1.15	φ1.09	φ1.09	0.82 x 1.15	0.82 x 1.15	0.82 x 1.15
Cu/NbTi ratio	1.3	1.3	6.5	6.5	1.3	1.3	1.3
No. turns	9124	2778	1305	1305	2778	6830	1216
Current (A)	162	182	109	109	155	132	271
Bmax (T)	7.2	5.2	3.1	3.0	4.8	5.4	7.4 (6.5)
Ic (A)	203	298	229	233	278	223	349
Iop/Ic	0.80	0.61	0.47	0.47	0.56	0.59	0.78
Inductance (H)	34.0	4.0	1.0	1.0	4.0	20.0	6.9

Amount of the liquid-He is assumed to be ~500 L. The cryostat is equipped with two small GM refrigerators for 4 k and 70 K stages and operated without supplying liquid He after poured once. In addition, to increase the cooling power at 4K, we will use two GM-JT refrigerators, which have total cooling power of 10W at 4K. The nine current leads made of high temperature superconducting material are used to minimize the heat load to 4 K stage. The heat load to 70 K stage is 160 W caused by copper current leads, supports of a cold mass and radiation through the multi-layer insulation.

The maximum electromagnetic force between the magnetic shields and the cold mass is estimated to be 8 tons in axial direction. The cold mass is supported with the belts from an outer tank in room temperature. Four belts with a cross-section of 300 mm^2 are used for the axial direction to support the axial force up to 10 tons. On the other hand, eight belts with a cross-section of 80 mm^2 are used for each of the vertical and horizontal directions to support up to 5 tons. The six solenoids and the hexapole coils are excited individually with seven power supplies. The solenoid coils are excited through seven high temperature superconducting current leads. The current lead between two adjacent solenoids is used to reduce the heat load. The diodes are placed in the liquid He vessel to protect the coils when any of the high Tc current leads breaks.

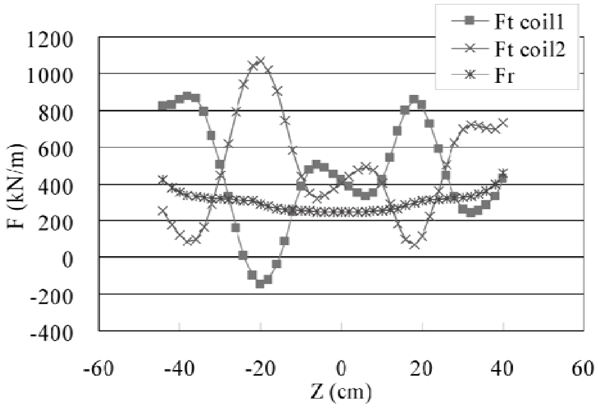

Fig.6. Longitudinal distributions of the magnetic force acting on the straight region of the hexapole coils

Excitation test

After the solenoid and hexapole coils were assembled, the excitation tests were performed in a cryostat. Both ends of all coils of the solenoids and the hexapole were connected with clamp diodes placed in liquid helium for the quench protection. Each solenoid coil achieved the design current without a quench.

Next, the hexapole coils was tested. Table 2 shows the currents when a quench occurred in the hexapole. The hexapole also achieved the design current (271A) after two quenches (189A, 255A) when no solenoids were excited.

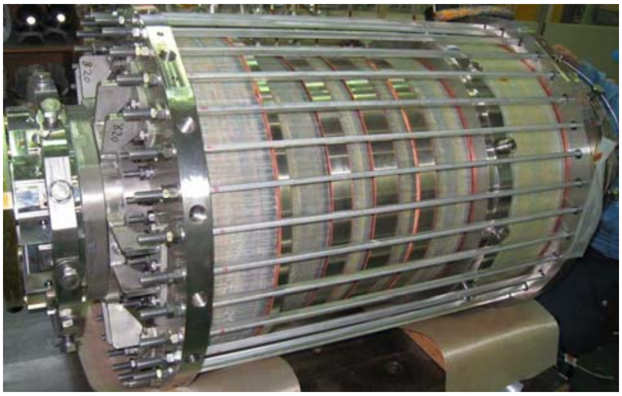

Fig.7. Picture of SC-coils

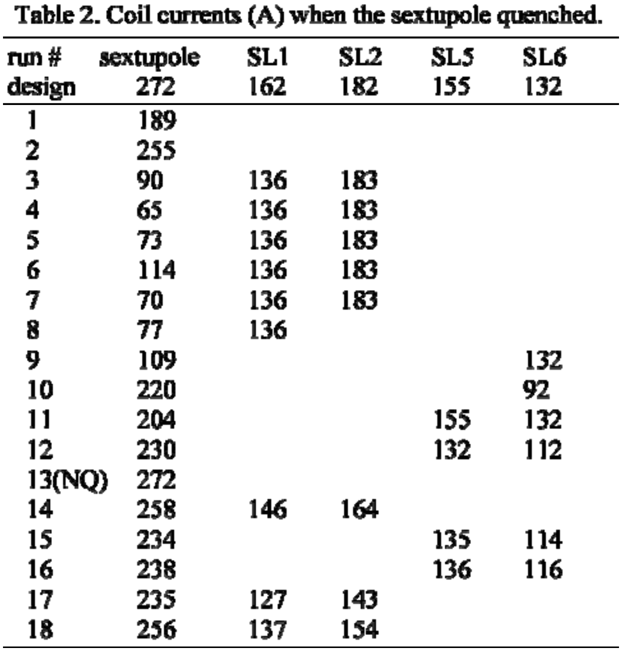

Table 2. Coil currents (A) when the sextupole quenched.

run #	sextupole	SL1	SL2	SL5	SL6
design	272	162	182	155	132
1	189				
2	255				
3	90	136	183		
4	65	136	183		
5	73	136	183		
6	114	136	183		
7	70	136	183		
8	77	136			
9	109				132
10	220				92
11	204			155	132
12	230			132	112
13(NQ)	272				
14	258	146	164		
15	234			135	114
16	238			136	116
17	235	127	143		
18	256	137	154		

In the combination tests in which the hexapole and one or two of the solenoids were excited at the same time, the hexapole coils quenched in all cases. The hexapole quenched at low currents ranging from 65 A (24%) to 115 A (42%) when the SL1 and the SL2 were excited at their design currents in advance (run #3~#7). The hexapole coils also quenched similarly when the SL6 was excited in advance (run #9, #11). A cause of these quenches was presumed to be a coil motion at the ends of the hexapole coils from the voltage signals, which observed in some of these runs. In run #10, the SL6 was ramped after the hexapole coils was excited at 220 A.

In run #12 and #14~#17, the solenoids and the hexapole coils were excited simultaneously keeping a ratio of the currents. In this case the direction of the force acting on the hexapole coils did not change during the excitation. The quench current of the hexapole increased to more than 85% of the design value in this way. It, however, was difficult to reach the design current. We have thus concluded that it is necessary to reinforce the structure at the ends of the hexapole coils.

PLASMA CHAMBER

Two turbo-molecular pumps (1100L/sec) are placed at the RF injection side and beam extraction side to keep the high vacuum of the plasma chamber (~10^{-8} Torr). The maximum extraction voltage is 40kV. The position of extraction electrode is remotely controlled. The high temperature oven is inserted from the RF injection side. To set the oven on the optimum position, the position of oven is also remotely controlled. The negatively biased disc is placed in the axial direction and its position is remotely controlled with the accuracy of 0.1 mm.

The inner diameter and outer diameter of the plasma chamber are 150 and 162 mm, respectively. The chamber is made of double wall stainless steel tube with the water cooling channel in between. To keep the high voltage (40kV max), the kapton sheet (total thickness of 2mm) covers the plasma chamber. For high voltage test, we could easily supply 40kV to the plasma chamber and kept it for 1hour without high voltage break.

LBL group demonstrated that the temperature of the cryostat increases with increasing the RF power in case of 28GHz.[9] It is due to the high energetic X-ray form the ECR plasma. To minimize the X-ray effect when using 28GHz microwave, the plasma chamber is covered by the 2mm thick Ta sheet.

LEBT for SC-ECRIS

Although we planed to construct a new injector system for injecting the U beam into the RIKEN ring cyclotron, we will start for construction in 2009 at the earliest and it takes several years. In order to supply the intense U beam to the experimentalist as soon as possible, we will install the SC-ECRIS on the existing high voltage platform of RIKEN heavy ion linac, which was used for injecting the heavy ion beam into the linac, before construction of the new injector. For injecting U^{35+} beam into the linac, we need the acceleration voltage of ~130kV.

After the extraction of the beam at 30kV, the solenoid coils is used for focusing the beam. Design of the 90-degree analyzing magnet is based on the LBL one [10]. The vertical gap and bending radius are 150 mm and 510 mm, respectively. The ion source, solenoid coil, and bending magnet will be installed on the high voltage platfrom. The U^{35+} beam (energy of 130qkeV) will be transported from high voltage terminal to the first acceleration tank of Riken heavy ion linac.

These ion beams are accelerated by accelerator complex of RIKEN RIB factory project up to 345MeV/u.

PLANED SCHEDULE

The excitation test after modification of sc-coils will be done in middle of September 2008. After second text experiment, the superconducting coils will be installed in the cryostat. Final acceptance test of the magnet will be concluded by beginning of December 2008. The ion source assembling will be done in December 2008. 90deg. analyzing magnet is constructed by end of January 2009. After assembling, the ion source and analyzing magnet will be installed on the high voltage plat home.

The first plasma will be obtained in spring 2009 using two 18GHz microwaves power supply (total output power of 3kW)

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