FIXED-FREQUENCY RING CYCLOTRON (fRC) IN RIBF

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Abstract

In the RIBF project one main purpose is to supply high intense U beam of 350 MeV/u from the SRC. The fRC is a four-sector room-temperature ring cyclotron located between the RRC and the IRC in order to accelerate very heavy ion beams such as Xe and U up to 50.7 MeV/u. From a view of cost the fRC is operated with fixed frequency (55 MHz; harmonics number = 12). The fRC is under construction. It will be installed from june in 2005 and the first commission will be planned in September of 2006.

ACCELERATION SCHEME IN RIBF

The RIKEN RI-beam factory (RIBF) is an accelerator complex to supply ion beams with energy more than 350 MeV/u for all stable nuclei and to produce great variety of RI-beam [1]. The accelerator complex composes of an existing linac (RILAC), an existing ring cyclotron (RRC) and three new constructing cyclotrons (fRC, IRC and SRC). Figure 1 shows an acceleration scheme in the RIBF [2]. As shown in Fig. 1, middle heavy ions (< Xe) are stripped to high charge-states by a charge stripper in upstream of the RRC and accelerated upto 46.3 MeV/u by the RRC to send into the IRC directly. In the case of very heavy ions(> Xe), however, high charge states needed for the acceleration scheme above mentioned are very low fraction at the charge stripper in upstream of the RRC. For this reason very heavy ions are accelerated upto 11 MeV/u by the RRC without using the stripper in upstream of the RRC and lack energy in order to send to the IRC is boosted up by the fRC, which is operated with fixed frequency, after passing through a charge stripper in upstream of the fRC. These beams are sent to the IRC via a charge stripper again. In the case of U ion beam as illustrated in Fig. 1, $^{238}U^{35+}$ obtained from 18 GHz ECR ion source is accelerated upto 11 MeV/u by the RRC and boosted upto 50.7 MeV/u by the fRC and 115 MeV/u by the IRC after charge-stripping to each favourable charge state at the charge strippers in upstream of each cyclotron. This beam is also accelerated upto 350 MeV/u by the SRC. Charge states in the fRC and IRC are 71+ and 88+ and expected fractions are 1/5 and 1/3 respectively.

SPECIFICATION OF fRC

The fRC is a four-sector ring cyclotron operated with fixed frequency unlike other cyclotrons in the RIBF from aspect of construction cost. Moreover, in order to make correction of magnetic field small, ion beams are accelerated with very close charge-to-mass ratio.

Main specifications of the fRC are summarized in Table. 1. Injection and extraction energies(11.0 and 50.7 MeV/u) of the fRC are determined so as to match to the RRC and the IRC including compensation of energy losses in the charge strippers in upstream and downstream of the fRC. K-value of the fRC is 570, which corresponds to acceleration of 50.7 MeV/u for $^{238}U^{71+}$. Frequency of the fRC is determined at 55 MHz, which is as 3 times as that of the RILAC and the RRC, so as to obtain high voltage in main RF cavity with small size and power. Harmonic number and injection radius of the fRC are chosen 12 and 1.55 m to match beam structure from the RRC. Extraction radius is determined 3.30 m from velocity gain (2.13) in the fRC. Sector angle is chosen 58^o with consideration of beam focusing in the fRC and determined maximum magnetic field is 1.68 T. In these specifications operating points of the fRC are 1.06 ~ 1.11 for ν_r and 0.68 ~ 0.74 for ν_z respectively. Acceleration voltage per one turn is 0.7 ~ 1 MV by use of 2 RF cavities to obtain large turn separation. Since the fRC is operated with frequency as 3 times as that of the RRC a flat-top cavity is also equipped in the fRC to make phase acceptance large ($\pm 10^o$).

The fRC will be located in the E4 room of the Nishina Memorial building. The beam from the RRC is horizontally injected into the fRC through a valley box. The beam is accelerated with clockwise direction and sent to the IRC after extraction through a hole in a yoke of the sector magnet.

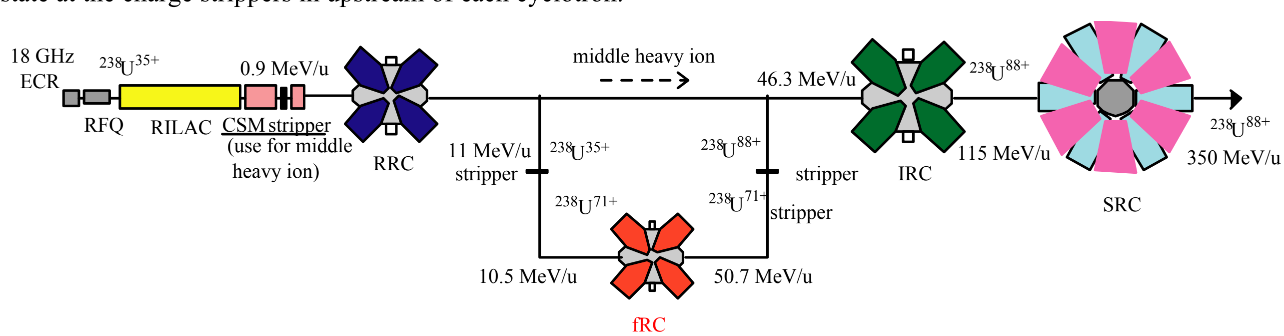

Fig.1 : Acceleration scheme in the RIBF

Table. 1 : Specifications of the fRC

K Value	570
Energy (MeV/u)	
Injection	10.5
Extraction	50.7
Frequency (MHz)	55
Harmonics	12
Radius (m)	
Injection	1.55
Extraction	3.30
No. of sector	4
Sector angle (degree)	58
Max. magnetic field (T)	1.68
ν_r	1.06~1.11
ν_z	0.68~0.74
Acceleration voltage (MV/turn)	0.7 ~ 1
Phase acceptance (degree)	±10

EACH SECTION OF fRC

Layout of the fRC is shown in Fig. 2. As shown in Fig. 2, the fRC composes of 4 sector magnets [3], 2 main RF cavities, a flat-top cavity, injection and extraction channels, beam diagnostics, and a vacuum system. In this section, each section of the fRC will be mentioned briefly.

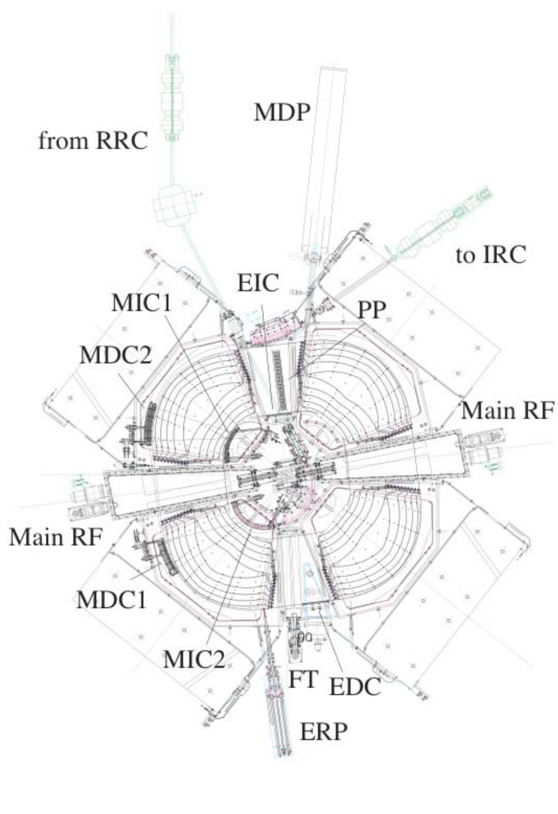

Fig. 2: Layout of the fRC.

Sector magnet

Each sector magnet consists of a pair of main coil, ten pairs of trim coils, poles and a yoke. Weight of the sector magnet is about 370 t and height is 4.38 m. Gap of the magnet is 50 mm and medium plane is 1.7 m from floor to match with existing beam line.

Isochronous magnetic field of the fRC is made of main and trim coils in the magnet and change of field length by radius. For this reason sector angle of the magnet is not constant value (average value = 58^{o} as shown is in Table. 1). Number of turns of the main coil is 70 and maximum ampere-turn of the main coil is 90 kAT. The main coil of every sector magnet is connected with a power supply seriously. The trim coils of one sector magnet consist of 6 pairs with maximum current of 200 A and 4 pairs with that of 100 A. Power supplies of the trim coils are prepared 24 for 200 A and 8 for 100 A in order to do small corrections of A/q difference as well as construction and alignment errors.

Upper and bottom poles of the sector magnet form a part of a vacuum chamber due to limitation of construction height. For this reason surface of each pole is coated by thin Ni to avoid outgas from iron. Every yoke located in mid-plane of the magnet has 2 holes. One is used for path of extracted beam as shown in Fig. 2 and surrounded by magnetic shield (80 mmϕ and 5 mm thickness). This hole is opened for all sector magnets with consideration of symmetry for magnetic field. Another is located in symmetry line of the magnet and used for measurement of magnetic field. In the gap of the sector magnet at opposite side where magnetic injection channel (MIC2) is located, a dummy magnetic channel is also located to keep symmetry.

RF system

RF system composes of 2 main RF cavities and 1 flat-top cavity and are located at valley sections as shown in Fig. 2. The main cavity has single acceleration gap and its maximum voltage is 350 ~ 500 kV (depend on radius) with maximum consumption power of 100 kW. The flat-top cavity is 3f-type and driven with 165 MHz. Maximum consumption power of the flat-top cavity is 30 kW. Each cavity has a fine tuner that correct change of frequency originated from construction errors and change of temperature.

Vacuum system

Vacuum system composes of 6 cryopumps used for main evacuation and 2 sets of turbomolecular and rotary pumps and 2 sets of mechanical-booster and rotary pumps used for rough evacuation. In each valley box with the main RF cavity, 2 cryopumps are located and in the other 2 valley boxes, 2 cryopumps is located. Evacuation volume of one cryopump is 13000 l/s to achieve 10^{-6} Pa.

Beam diagnostics

In the fRC 1 main radial probe (MDP), 1 phase probe (PP), 1 extraction radial probe (ERP), some slits and Faraday cups are mainly prepared as beam diagnostics. The MDP is a distractive probe that almost moves from injection radius to extraction radius and can measure beam current cut by step of 0.5 mm for radial direction. The MDP can also measure the remaining part that does not cut. The ERP is almost the same probe as the MDP and can measure beam current in extraction region. The PP is 14 pairs of parallel plate pick-up with gap of 30 mm. In one pair of pick-up about 10 turns of beam pass through. The PP measures phase by timing of the beam passing through the pickups. This information is used for fine- tuning to make isochronous magnetic field. Slits are located at entrance of each magnetic channel. These slits are separated in 4 parts (up, down, left, and right) that can read beam current roughly. Faraday cups are located near middle radius and extraction and used for measurement of transmission.

Injection and Extraction channels

As shown in Fig. 2, injection and extraction channels are composed of 2 magnetic and 1 electrostatic channels respectively. Main specifications of each channel are summarized in Table. 2. As shown in Table. 2, magnetic fields of magnetic channels for injection are the same direction as that of the sector magnet and those for extraction are the opposite direction. Each magnetic channel has correction coils to avoid appearance of magnetic filed in acceleration orbit. The EIC has a hole for injection beam. Position of each channel can be moved.

Table. 2. Main specifications of the injection and extraction channels.

Magnetic channels			
Name	Radius (m)	Max. magnetic field (T)	Bending angle (degree)
MIC2	0.72	0.16	80
MIC1	0.87	0.16	40
MDC1	2.15	-0.06	19
MDC2	2.30	-0.14	20
Electrostatic channels			
Name	Gap (mm)	Max. Voltage (kV)	Length (m)
EIC	12	120	0.5
EDC	12	120	0.55

SCHEDULE

The fRC is now under construction. The sector magnet is almost completed. The valley boxes including with the main RF cavity will be completed by March in 2005. Installation in E4 room of Nishina building will start from June in 2005. The first commission will be planned in September in 2006.

REFERENCES

[1] Y. Yano, in this proceeding.
[2] H. Ryuto et.al. , in this procrrding.
[3] T. Mitsumoto et.al. , in this proceeding.