THE IPCR SEPARATED SECTOR CYCLOTRON PROJECT

presented by H. Kamitsubo

The Institute of Physical and Chemical Research

Abstract

Construction of a separated sector syclotron(SSC) was started at IPCR (Riken) this year. It is the main accelerator of the multipurpose accelerator complex which is composed of the SSC and two independent injectors(heavy-ion linac and AVF cyclotron). The beam energy ranges from 135 MeV/u for fully-stripped light ions to 14 MeV/u for very heavy ions such as uranium.

Introduction

Since 1966 the 160 cm cyclotron at IPCR has been used for multidisciplinary studies. However its capabilities are rather limited and a more powerful machine has been required to extend these studies. In 1972 an accelerator complex composed of a separated sector cyclotron and two independent injectors was proposed. Construction of injector linac[1]) was started in 1974 and finished recently. The proposal[2]) for the energy booster of the linac was approved by the government last year and the final design studies are now in progress. The design goal is to achieve maximum beam energies of 135 MeV/u for fully-stripped light ions and typically 14 MeV/u for very heavy ions like uranium. Energy variability down to 10 MeV/u should be realized. High intensity beams of protons, deuterons and α particles of intermediate energies are also required for studies of nuclear chemistry and radiation biology as well as nuclear physics. The beam quality(mainly intrinsic energy spread and emittance) has to be as high as possible.

General description

Examples of some operating parameters at the maximum energies of the accelerator complex are given in table 1. The linac usually accelerates ions in the fundamental mode(i.e.harmonic number h=1) in the frequency range of 17-45 MHz. Considering the matching condition of the resonance structure of the beam and the available magnetic field strength of the SSC, we take dee angle of 20° for the SSC. Then the harmonic number in acceleration in the SSC is 9 and the frequency range is the same as that of the linac. On the other hand, the injector cyclotron will be operated in the orbit frequency range of 2.7-7.5 MHz. The harmonic numbers of 3 and 6 are favourable for the cyclotron and the SSC, respectively.

The above values of the harmonic numbers are different from those in ref. 2. The harmonic number was increased because we reduced the maximum magnetic field of the SSC from the energy saving point of view. The maximum value of B_{inj} was reduced from 1.7 T to 1.5 T and the injection radius was increased to 0.89 m. The beam from the linac should be transfered by about 60 m to the SSC. The beam transfer system between the injectors and the SSC was designed to transport the beam and to match the beam quality to the acceptance of the SSC without any beam loss. As for the injection to the SSC, the axial injection method was employed. The advantage of this method is described ref.3.

Separated Sector Cyclotron

The main characteristics of the SSC are shown in table 2. The SSC has four sectors of 50° with straight edges. The sector magnet and 30 trim coils yield the required idochronous field of 1.67 T at maximum. The focusing properties of the SSC are calculated with the computer code developed by N. Nakanishi by using measured field distribution for a pair of a qurter scale model magnets[4]). In order to avoid the betatron oscillation resonances during acceleration, we have chosen the region defined by $\nu_r - 2\nu_z = 0$ and $\nu_r = 4/3$ at high energy side.

Ions are accelerated by 20° delta-shaped two dees located at opposite valley spaces between the sector magnets. The frequency range of the RF system is chosen to be 17-45 MHz to realize a synchronous operation with the linac. RF electric field distributions and quality factors were measured for a half scale model cavity for the whole range of frequency. The effective accelerating voltage for the cyclotron injected beams will be $\sqrt{3}/2$ of that for the linac injected beams.

The beam from the injectors is brought slantingly into the SSC through the valley and bent by 45° into the median plane in the central region. Then it is inflected by 100° with a bending magnet into a magnetic inflection channel in the pole tip of the sector magnet. The second magnetic inflection channel and an electrostatic inflector bring the beam onto the first equilibrium orbit.

The operating pressure of 1×10^{-7} Torr is desirable in the median plane of the SSC to limit beam losses due to charge-excange less than about 10 % in case of very heavy ions. The vacuum chamber consists of 2 delta-shped resonators, 2 valley chambers and 4 chambers positioned at the sector magnets. The total degas rate from the surface of the chambers has been easimated to be about 2.5 lus. Two cryopumps of 25000 l/s and two titanium-sublimation pumps of 5000 l/s, for example, will be needed to reach the above mensioned vacuum.

Injectors

The heavy-ion linac at IPCR will be used as an injector of heavy ions with final energy up to 60 MeV/u. Main characteristics of the linac is described in ref. 1. For heavy ions with final energy greater than 60 MeV/u as well as light particles such as deuterons and α particles, an AVF cyclotron is chosen to be an appropriate injector. The Maximum mean field of the proposed AVF cyclotron is 1.3 T, the energy constant being K=90 MeV. It is possible to accelerate p, d, h and α as well as heavy ions up to Ar with the harmonic numbers of 2 and 3. The maximum injection energy into the SSC is limited to 7 MeV/u for heavy ions and 10 MeV/u for d, h and α. Main characteristics are given in table 2.

Building

This facility will be devoted to researches in various fields such as nuclear and atomic physics, solid state physics, material science, nuclear and radiation chemistry, radiation biology and RI production. The use for the radiotherapy is also being considered. All facilities for these purposes are being planned to be constructed at IPCR. Tentative layout of the beam lines and main facilities together with plan views of the SSC and the AVF cyclotron is shown in Fig.1.

In order to keep the radiation dose as lower as possible at the boader of the campus of IPCR, thickness of the concrete wall and ciel of the SSC vault should be 4 m and that of other vaults should be 3 m. The shielding effect and the radiation doses at various points both inside and outside of the building are calculated.

Planning

The four sector magnets will be ordered in this fall. Design study of the RF system,computer controle system and extraction and beam lines to the experimental facilities will be continued.

The first beam will be expected in 1985. This facility will be open not only for the inside users but also for outside users.

References

1) M.Odera,"Status Report of Rilac, Riken Variable Frequency Heavy-Ion Linac" this conference.
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3) Y.Yano et al, "Design of Injection System for the IPCR SSC (I)", this conference.
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Table 1 Examples of some operating parameters at the maximum energies in the propoed accelerator complex

LINAC						SSC							
Beam	Charge	m/q_1	Accelerating RF freq. (MHz)	Accelerating RF voltage (MV)	Energy per nucleon (MeV/u)	Charge (q_2)	m/q_2	B_{inj} (Wb/m^2)	B_{max} (Wb/m^2)	Orbit freq. (MHz)	RF Accelerating freq. (MHz)	h number	Energy per nucleon (MeV/u)
^{40}Ar	8+	5	44	20	3.8	15+	2.7	1.45	1.55	4.8	43.3	9	66.6
^{84}Kr	9+	9	33	20	2.2	24+	3.5	1.45	1.5	3.67	33	9	36.8
^{132}Xe	9+	15	26	20	1.36	30+	4.4	1.43	1.46	2.88	26	9	22.3
^{238}U	10+	24	20.4	20.4	0.84	37+	6.4	1.55	1.57	2.14	19.4	9	12.2
						40+	5.9	1.52	1.54	2.27	20.4	9	13.6

Cyclotron ($\bar{R}_{ext}$=0.893 m)						SSC							
Beam	Charge	Orbit freq. (MHz)	RF freq. (MHz)	B_{ext} (Wb/m^2)	Energy per nucleon (MeV/u)	Charge (q_2)	m/q_2	B_{inj} (Wb/m^2)	B_{max} (Wb/m^2)	Orbit freq. (MHz)	RF Accelerating freq. (MHz)	h number	Energy per nucleon (MeV/u)
P	1+	7.37	22.1	0.485	9	1+	1	0.838	0.994	7.37	44.2(29.5)	6(4)	184
^{3}He	2+	7.37	22.1	0.727	9	2+	1.5	1.26	1.49	7.37	44.2(29.5)	6(4)	184
^{12}C	4+	6.51	19.6	1.28	7	6+	2	1.48	1.67	6.5	39.1(26.0)	6(4)	134.6

Table 2 Characteristics of Separated-Sector Cyclotron

Maximum energy for $U^{37+}(U^{40+})$	13.6 MeV
Maximum energy for C^{6+}, O^{8+}, Ne^{10+}	135 MeV/u
Number of sectors	4
Sector angle	50°
Magnet fraction	0.555
Magnet gap	8 cm
Maximum Magnetic field	15.5
Main coil power	450 kW
Number of trimming coils	30
Magnet weight	2300 ton
Injection mean radius	89.3 cm
Extraction mean radius	373 cm
E_f/E_i	16∿18
Number of dees	2
Dee angle	20°
Peak voltage	250 kV
RF power	300 kW x 2
RF frequency range	17 45 MHz
Number of harmonic Acceleration	(4), 6,9

Characteristics of Injector Cyclotron

Energy constant, K	90
Number of sectors	4
Magnet gap at hill	∿20 cm
Maximum mean magnetic field	13 kG
Extraction mean radius	89.3 cm
Main coil power	200 kW
Number of dees	2
Dee angle	60°
RF frequency range	7.5∿22.5 MHz
Maximum RF voltage	50 kV
RF power	150 kW

Fig. 1

(1) SSC vault

(2) Injector cyclotron

(3) Material science

(4) Nuclear spectroscopy

(5) Radiation therapy and radiation biology

(6) Nuclear chemistry and RI production

(7) Atomic and solid state physics

(8) Nuclear physics

(9) Beam transport lines