INJECTOR AVF CYCLOTRON AT RIKEN

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Abstract

A K70 AVF cyclotron is under construction to be used as an injector of light and light heavy ions for the K540 RIKEN Ring Cyclotron (RRC) that was completed in November, 1986. The AVF cyclotron has four spiral sectors and two RF dees with an angle of 85°. The extraction radius and acceleration harmonics were chosen to be 714 mm and 2, respectively. Ions from external ion sources consisting of a duoplasmatron, an ECR source and a polarized ^3He ion source (in the stage of conceptual design) are axially injected into the cyclotron and led onto the median plane with a spiral inflector. This cyclotron can accelerate ions whose m/q value is up to 4. If an $^{40}Ar^{11+}$ ion is accelerated with this cyclotron, for example, the final beam energy from RRC reaches up to 95 MeV/u. It will be completed at the end of March, 1989.

Introduction

The RIKEN Ring Cyclotron (RRC) is designed to have two injectors for both light and heavy ions. After the completion of RRC in November, 1986, it has been routinely in operation coupled with RILAC, which offers mainly heavy ions [1]. An AVF cyclotron is expected to be used as an injector to get higher energies for light and light heavy ions. In coupled use with RRC, the final energies designed are 210 MeV for protons, 135 MeV/u for ^{12}C, ^{14}N, ^{16}O etc., 95 MeV/u for ^{40}Ar and so on.

Conceptual design of the AVF cyclotron is reported elsewhere [2]. At that stage the cyclotron was designed to be used not only as the injector for RRC but also as a stand-alone machine which can accelerate, for example, protons up to 60 MeV. The acceleration harmonic number was adopted to be 2 and 1 for each purpose. Recently, however, the harmonic number 1 designed for a stand-alone machine was abandoned because if both harmonic numbers are used the central region of the injection system will be very complicated. The model 750PV [3] of Sumitomo Heavy Industries, Ltd. (SHI) was decided to be purchased and to be modified to meet the requirements for the injector as well as an external injection.

Description of the AVF cyclotron

Table 1 gives the characteristics of the AVF cyclotron. Layout of the cyclotron is shown in Fig. 1 and its performance in Fig. 2.

Table 1 Characteristics of the AVF cyclotron

Number of sectors	4
Sector gap	127 mm
Pole gap	300 mm
Pole diameter	1,730 mm
Extraction radius	714 mm
Maximum magnetic field	1.7 T
Maximum main coil current	1,000 A
Maximum power	150 kW
Number of trim coils	9
Number of harmonic coils	4
Magnet size	2.1m(H)×1.9m(W)×3.9m(L)
Magnet weight	110 ton
Number of dees	2
Dee angle	85 deg
Frequency	12-24 MHz
Maximum dee voltage	50 kV
Maximum RF power	30×2 kW
Inflector	spiral type
Main evacuation system	4,000, 6,500 l/sec cryopumps 1,500 l/sec turbomolecular pump
Pressure	2×10^{-5} Pa
Control system	Computer network and CAMAC interfaces
Acceleration harmonic number	2

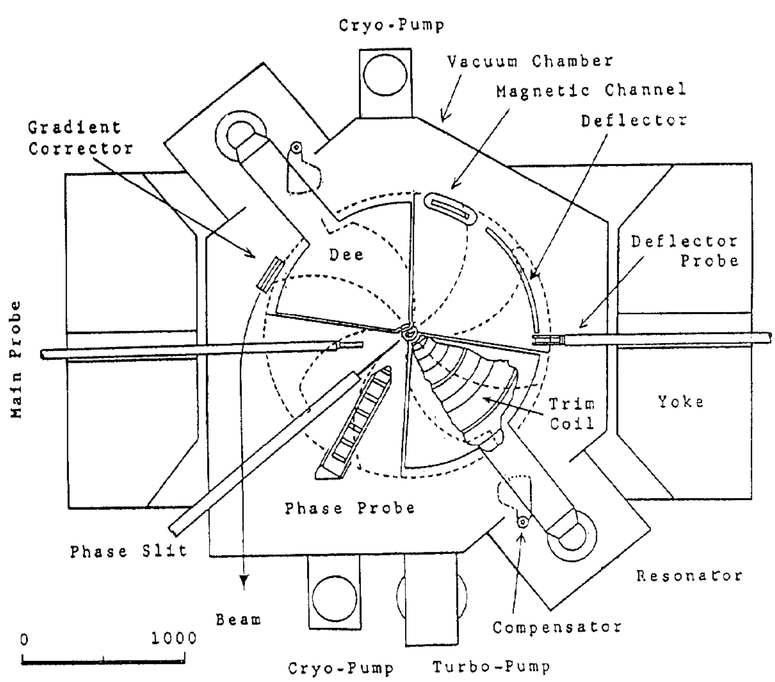

Fig. 1. Layout of the AVF cyclotron.

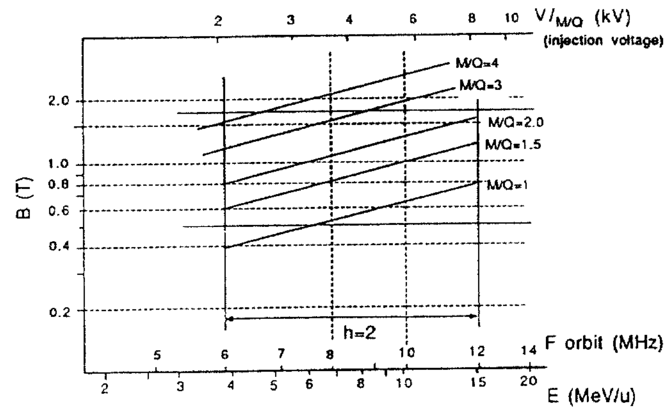

Fig. 2. Performance of the AVF cyclotron.

Magnet

The magnet is of the H-type with four spiral sectors. Pole diameter was chosen to be 1730 mm by taking account of the extraction radius of 714 mm, which was determined from the matching condition to RRC [2]. To compensate the reduction of magnetic field near the extraction radius at high excitation level, iron shim is attached to the side of the outer end of each sector. Nine pairs of circular trim coils are wounded on the sectors and four pairs of harmonic coils are placed in the extraction region of valley sections. Maximum currents of main coil, trim coils and harmonic coils are 1000 A, 360 A and 120 A, respectively. Plugs made of iron to produce a central field bump are set at the corner of the central holes through the upper and lower yokes.

Magnetic field measurement was made in April, 1988, at the factory of SHI. Field maps of base field were measured for six levels of main coil currents, and those of trim field were measured for maximum current of each trim coil at each level of main coil current. The azimuthal range of the map was 90° with an interval of 1.8° and the radial range was 800 mm with an interval of 20 mm. Measurement of 360° map was made with an interval of 100 mm to check the first harmonic component. Magnetic fields in the area in which an extracted beam passes and inside the hole of the yoke through which a beam from an ion source is injected were also measured. The average field of 17 kG at the extraction radius that is a designed maximum value was obtained at a main coil current of 970 A. Excitation level as well as flutter and vertical betatron frequency (ν_r) agreed well with the design. Although the unexpected first harmonic field appeared at higher excitation levels (several G at the maximum), it was found from the computer simulation that this is tolerable and the designed extraction energy can be obtained.

Injection / Injection Beam Transport

Layout of the injection beam transport system and the injection system is shown in Fig. 3. A beam is transported from the ion soruce that is situated in the room over the cyclotron vault, injected axially through the hole of the upper yoke and bent onto the median plane of the cyclotron by means of an inflector.

Three kinds of ion sources such as an ECR source, a duoplasumatron and a polarized ^{3}He ion source will be used. Among these the ECR soruce and the duoplasmatron have been completed and provide us with a good performance [4]. The polarized ^{3}He ion source is being developed. The 90° bending magnet with a function of double-focusing is used to bend horizontally a beam from the ECR source. The system consisting of two 45° bending magnets and three quadrupole singlets constitutes an achromatic one and bends a beam vertically down to the cyclotron. A beam emittance is shaped by use of the quadrupole quartet to match the acceptance of the cyclotron. Two Glazer lenses and a stereer are set inside the hole of the upper yoke. Basically, solenoids are used to focus a beam in this transport system. A beam buncher is placed at 2 m upstream from the inflector. The buncher has one gap made with two meshes, one of which is excited by an optimal combination of f_0, $2f_0$ and $3f_0$ giving a sawtooth-like wave. This is expected to make the bunching efficiency significantly high. Various beam diagnostic devices such as a slit, a profile monitor and an emittance monitor are located at due places. The diameter of beam tube is 110 mm. The tubes are covered with 2 mm thick iron plates to shield a magnetic field caused by the cyclotron because the injection voltage is very low (about 8 kV at the maximum).

The inflector is of the spiral type whose electric radius and magnetic radius are 26 mm and 16.3 mm, respectively. Gap between two alminum electrodes is 5 mm and voltages of up to ±5 kV are fed to the electrodes. The inflector is inserted through the hole of the lower yoke. It can be rotated by 5° and can be adjusted vertically by ±5 mm.

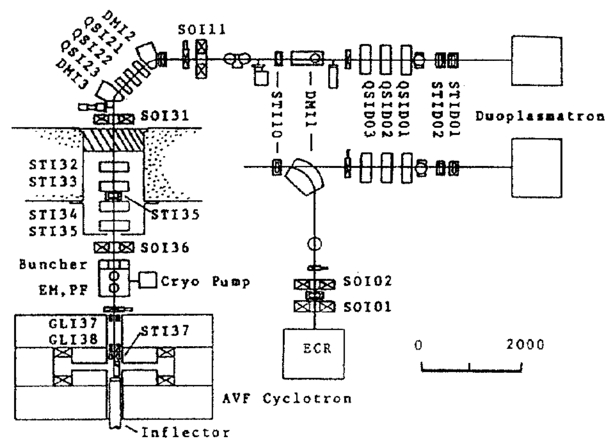

Fig. 3. Layout of the injection beam transport system and the injection system: ST-steerer, QS-quadrupole singlet, DM-dipole magnet, SO-solenoid, GL-Glazer lens, EM-emittance monitor, PF-profile monitor.

Central Region

One of the most significant changes from the 750 PV is that with respect to the central region of the cyclotron. To design this region, a computer program was developed that simulates a beam orbit and the acceptance of the cyclotron and so on. The requirements are that 1) a beam should be accelerated on a well-centered orbit, 2) the acceptances of the cyclotron in (r, r') and (z, z') phase spaces should be as large as possible and 3) the phase of a beam can be cut effectively with a phase defining slit. The optimal combination of the shape of a central field bump and the configuration of a central electrode of the RF resonator were searched to meet these requirements. The layout in the central rgion thus determined is shown in Fig. 4. This was designed only for the case of harmonic number equal to 2. Pillars are placed at the first two gaps. The nose part of the electrode in this region is remountable for maintenance or repair. A movable phase defining slit is set on the first turn inside the dummy dee. The computer simulation indicates

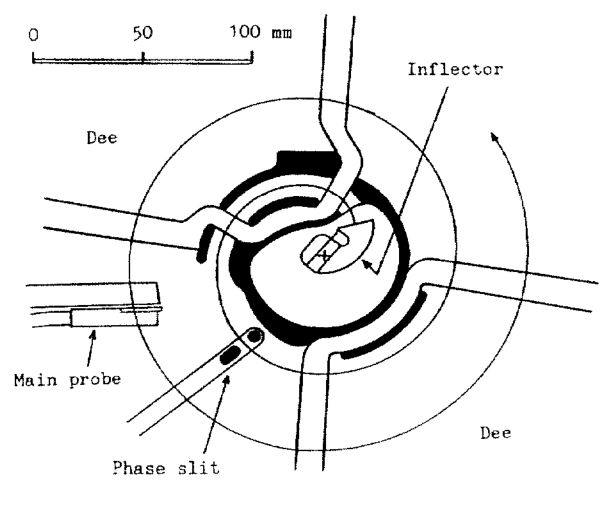

Fig. 4. Central region of the cyclotron.

that the slit is very effective because at this place not only a beam spreads radially according to the phase but also it shrinks with respect to the radial emittance as shown in Fig. 5. Peak of the central field bump is about 1 %. Calculated acceptance covers sufficiently an expected beam emittance from the ECR source of about 100 π mm.mrad.

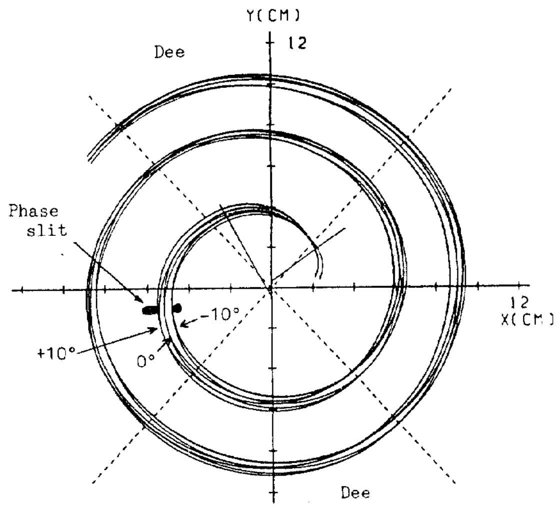

Fig. 5. Calculation of orbits in the central region. Orbits with 0° and ±10° RF, each having an emittance of +2.5 mm and +40 mrad, are simulated.

Extraction / Extraction Beam Transport

A beam is extracted by means of an electrostatic deflector and a magnetic channel. After the magnetic channel a gradient corrector is placed to focus a beam radially. The gradient corrector is of the passive type that produces inside it an opposite field gradient to that of the fringe field. The gradient is 1 - 2 kG/cm. The optimal parameters of these elements are currently being searched using the magnetic field data.

Layout of the extraction beam transport system is shown in Fig. 6. The details of beam optics of the system are given in Ref. [5]. A beam rebuncher is used to make a beam time-focused at the injection point of RRC. The resonator of the rebuncher is of the shielded Lecher-wires type with two stems. At the end of each stem a drift tube is mounted, which forms three gaps. The resonant frequency is twice that of RRC, i.e. four times that of the AVF cyclotron. The 90° bending magnet DMC1 is prepared to bend down a beam and deliver it directly to the experimental room for materials physics. Various beam diagnostic devices such as a slit, a profile monitor and an emittance monitor are located at due places.

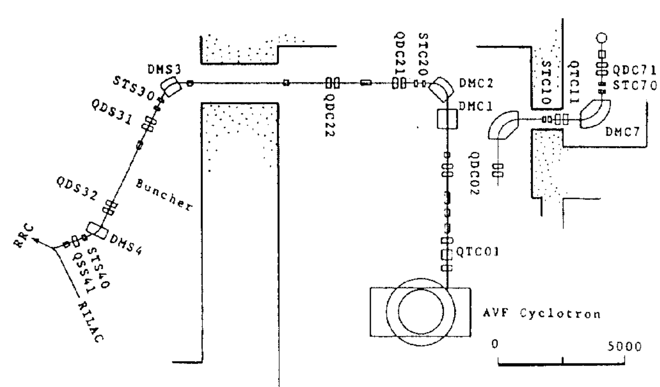

Fig. 6. Layout of the extraction beam transport system: ST-steerer, QS,QD,QT-quadrupole singlet, doublet and triplet, DM-dipole magnet.

RF

Two-dee system with a dee angle of 85° is adopted. The resonator is of the $\lambda/4$ coaxial type with a movable shorting plate. The resonant frequency is 12-24 MHz and the required voltage is 50 kV at the maximum. The acceleration gap is 12 - 24 mm (radially increasing) and the vertical aperture is 24 mm. Each resonator is excited with an amplifier chain of a 500 W wide-band amplifier, an all-pass network system and a 30 kW power tube. The combination of the wide-band amplifier and the all-pass network sytem is adopted instead of a power tube pre-amplifier because of easiness for operation and maintenance.

Beam Diagnostics

As shown in Fig. 1, a main radial probe, a deflector probe and a phase probe are placed inside the cyclotron for beam diagnostics. The main probe is inserted through the hole of the side yoke. Its stroke is 900 mm. The probe head has three finger-like electrodes for the differential measurement and an electrode for the integral measurement. A beam pattern near the extraction is measured with the deflector probe in front of the entrance of the deflector. Its stroke is 100 mm. The phase probe measures the relative phases of beams on different turns. It is designed to consist of six pairs of parallel plates. This probe will be very helpful to get an isochronous field. In front of the entrance of the inflector a buffle slit divided into four leaves is placed to get information on whether a beam clears the element or not. A buffle slit vertically divided into two is placed in front of the electrode of the deflector, and that horizontally divided into two is attached to the entrance of the magnetic channel and the gradient corrector.

Vacuum

The vacuum chamber is made of alminum. Two cryopumps of 6,500 and 4,000 l/sec and a turbo-molecular pump of 1,500 l/sec are used to evacuate the chamber down to the pressure of 2×10^{-5} Pa. Because trim coils and harmonic coils are sources of outgassing, they are sealed with the grounded plate from the high vacuum. The pressure inside this section is 10^{-2} - 10^{-3} Pa.

Control

All the system of the cyclotron is remotely controlled and monitored by means of the same computer control system as that of RRC [6].

Concluding Remarks

Construction of the AVF cyclotron is underway without a great delay of the schedule. The ECR source has already been completed. The magnetic field measurement performed in April, 1988, shows that the performance of the magnet system is as good as expected. All parts of the cyclotron will be assembled at the factory of the company by the autumn of 1988 and various tests such as a leak test, a moving test and RF test will be made there before the installation into the cyclotron vault of RIKEN. The installation and assembly of the cyclotron at RIKEN is scheduled to be completed by the end of March, 1989.

References

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