STUDY OF BEAM OPTICS FOR THE INJECTOR AVF CYCLOTRON AT RIKEN

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ABSTRACT

Study of beam optics is described for the K70 AVF cyclotron, which is an injector of the K540 RIKEN Ring Cyclotron (RRC) and was completed in March 1989. Beam optics in the injection and extraction beam transport lines is also discussed.

1. INTRODUCTION

The injector AVF cyclotron[1] is a type 750PV[2] of Sumitomo Heavy Industries, Ltd (SHI), modified so as to be used as an injector of the RIKEN Ring Cyclotron (RRC). This cyclotron is equipped with external ion sources such as an ECR source and a duoplasmatron, and adopts an axial injection scheme. Consequently, one of the most significant modifications to the 750PV is the central region of the cyclotron. In studying the beam optics in the cyclotron including the central region, effort was focused to offering RRC a beam of good quality.

2. INFLECTION/CENTRAL REGION

To design this region, a computer program has been developed that simulates a beam orbit, the acceptance of the cyclotron, and so on. Principal requirements are 1) a beam should be accelerated on a well-centered orbit, 2) the acceptances of the cyclotron in a (r,r') and a (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 was searched to meet these requirements.

The layout of the central region thus determined is shown in Fig. 1. An inflector of the spiral type[3] is adopted to bend a beam onto the median plane. The optimized K value is 0.8 with R_e= 26 mm and R_m= 16.3 mm. The peak of the central field bump is 1 %. The isochronous field region is designed to start around a radius of 20 cm. Drift-tube-like pillars, which have a rectangular aperture, are placed at the first two gaps. For the electric field distribution in the dee gap, a Gaussian function given in Ref.4) was used. A vertical component of the electric field was given by the derivative of the Gaussian function. As for the drift-tube-like pillars, a radial component of the electric field was further taken into account. Figure 2 shows the

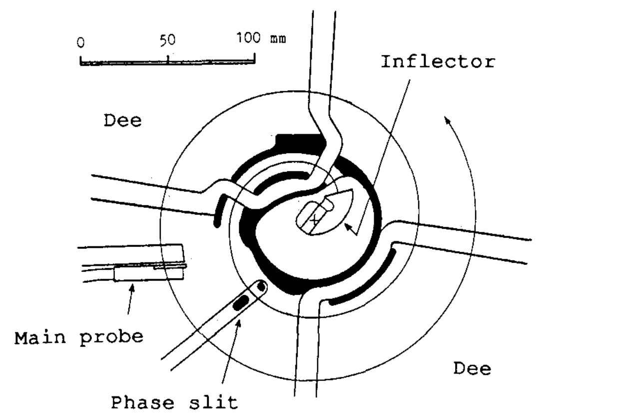

Fig.1. Schematic drawing of the central region of the AVF cyclotron.

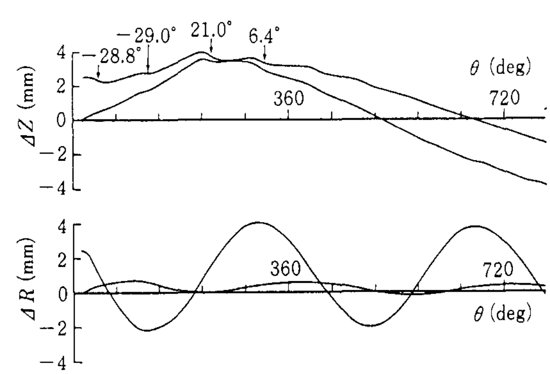

Fig.2. Motions of two particles in both horizontal and vertical directions for the first two revolutions. The two particles are orthogonal to each other lying on the phase ellipse whose area is πx2.5mmx40mrad. Arrows and values indicate the positions of the first four gaps and the rf phases when the particles pass through the gaps.

motions of selected two particles in both horizontal and vertical directions for the first two revolutions. Acceptances of the cyclotron in both directions are shown in Fig. 3 for various injection phases. This figure indicates that the calculated acceptances within injection phases of ±5° or more cover an expected beam emittance of about 100π mm.mrad from the ECR source. (Note that the gap of the inflector is 5 mm.) Here the definition of acceptance is given by that, up to a radius of 20 cm, particles should lie within the distance of ± 5 mm and ±10 mm from the central particle in the horizontal and the vertical directions, respectively. A movable phase defining slit is set in the first turn inside the dummy dee. The computer simulation indicates that the slit is very effective because at this place not only a beam spreads radially according to phase but also it shrinks with respect to the radial emittance as shown in Fig.4.

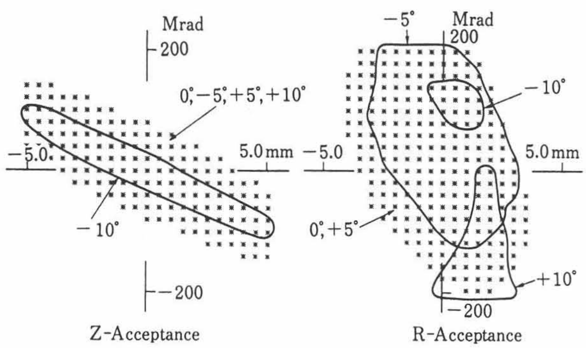

Fig.3. Acceptances of the cyclotron in both horizontal and vertical directions for various injection phases.

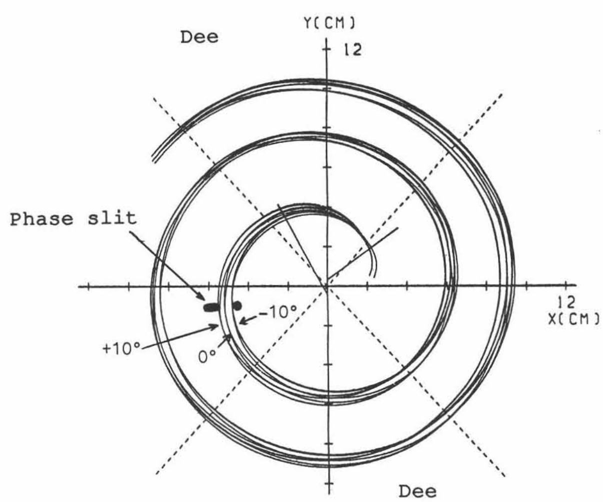

Fig.4. Dependence of trajectories for the first few revolutions on the injection phase. Trajectories with the injection phases of 0° and ±10° are simulated, each consisting of three particles: the central particle and two particles orthogonal to each other lying on the phase ellipse whose area is π×2.5mm×40mrad.

3. ACCELERATION SIMULATION

To study the beam behaviour in the cyclotron in detail, we have developed a computer program that simulates the motions of a number of particles simultaneusly. In this program the parameters of particles at the injection point (at the exit of the inflector) are randomly picked up from inside a six-dimensional phase ellipse. The density distribution inside the phase ellipse was assumed to be a Gaussian. The number of selected particles is 200. After every revolution all the parameters of these particles are stored in a computer memory.

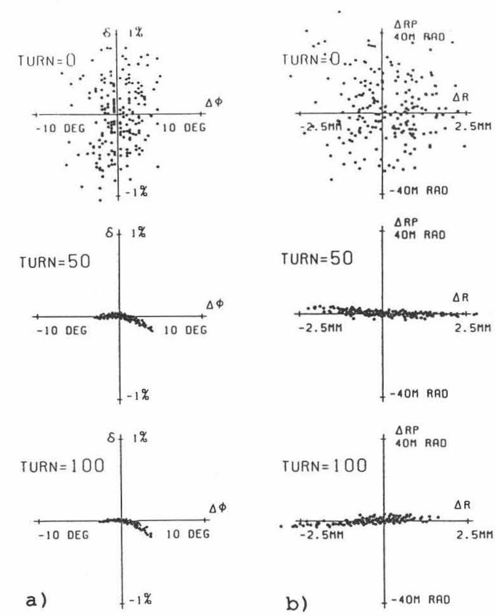

Fig.5. Motion of phase ellipse that is projected onto a) longitudinal and b) horizontal phase planes. The area of the initial phase ellipse is π×2.5mm×40mrad (horizontal and vertical) and π×10°×1% (longitudinal). The number of simulated particles is 200.

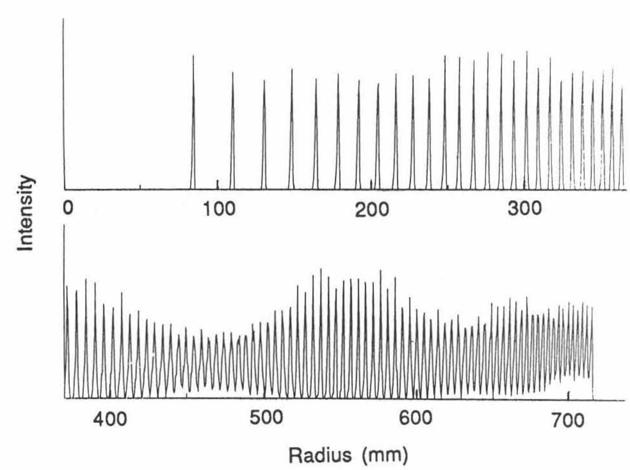

Fig.6. Simulation of orbit pattern for the same condition as that of Fig.5.

Figure 5 shows the motion of phase ellipse that is projected onto horizontal and longitudinal phase planes. Both the beam width and the phase width are recognized to slightly shrink according to the revolution. The simulation of orbit pattern is shown in Fig 6. A turn separation can be expected up to the extraction region. Figure 7 shows for comparison the orbit pattern measured in the first operation of the cyclotron.

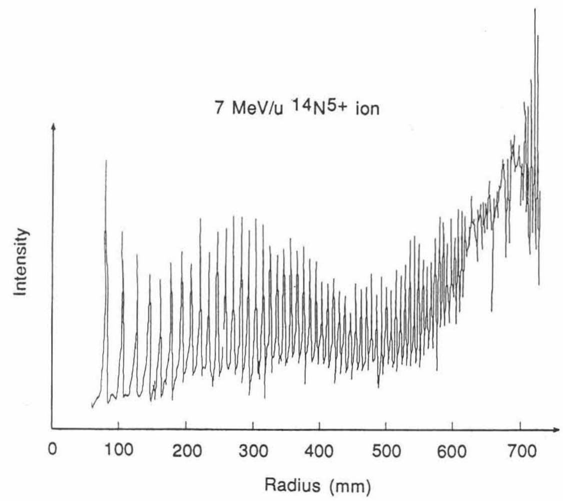

Fig.7. Measured orbit pattern for the first beam. The phase defining slit was set so as to pass particles within ±10°. Turn separation is seen up to the last revolution.

4. EXTRACTION

The beam extraction system consists of an electrostatic deflector, a magnetic channel, and a gradient corrector which focuses a beam horizontally. The gradient corrector is of a passive type. The layout of the system is shown in Fig.8 together with some other main components of the cyclotron.

To determine a beam trajectory in this system, we chose a 7 MeV/u $^{14}N^{5+}$ ion as a reference particle. This was an accelerated particle in the first operation this April. The initial beam parameters at the entrance of the deflector were obtained by tracing a group of particles from the exit of the inflector (the injection point). Emittances at the exit of the inflector were assumed to be πx2.5mmx40mrad, πx2.5mmx40 mrad, and πx6°x1%, in a horizontal, a vertical, and a longitudinal directions, respectively. The beam was traced along the extraction orbit from the entrance of the deflector up to the extraction hole of the vacuum chamber (at position A in Fig.8).

In general, the extraction orbit varies with the excitation level of the magnet, because the shape of fringe field distribution changes with the excitation level. The calculation showed that the beam position changes as large as about 8 mm at the entrance of the gradient corrector.

Beam sizes along the extraction orbit were also calculated. Figure 9 shows the change in the beam size in the horizontal and vertical directions. A horizontal focusing and a vertical defocusing with the gradient corrector can be seen from Fig.9. To see the effect of the gradient corrector, the beam sizes after the gradient corrector were calculated for several field gradients. The beam size in the horizontal direction was found to be strongly dependent on the strength as shown in Fig.10. The calculations for several excitation levels of the magnet showed that the beam size can be kept rather small with this gradient corrector of a passive type at all excitation levels despite its sensitivity on the strength.

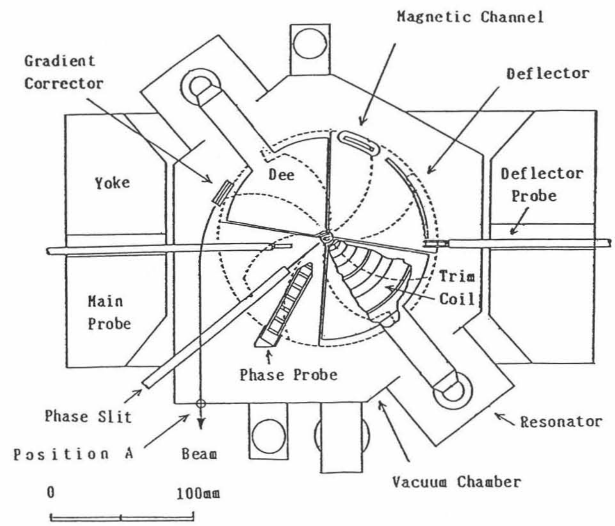

Fig.8. Layout of the extraction system together with some other componets of the cyclotron.

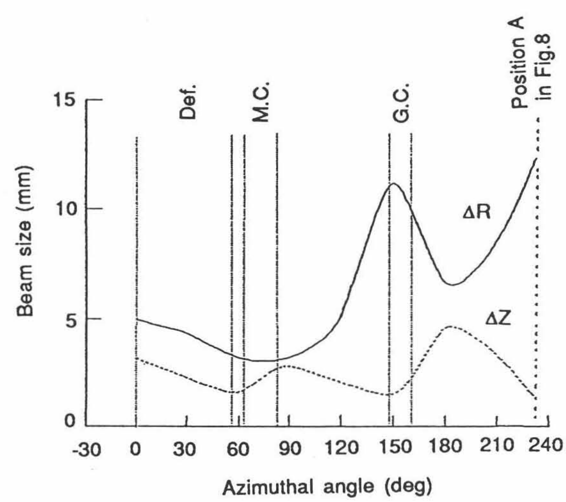

Fig.9. Beam sizes calculated along the extraction orbit in both horizontal (ΔR) and vertical (ΔZ) directions. The 7 MeV/u $^{14}N^{5+}$ ion was taken as an example.

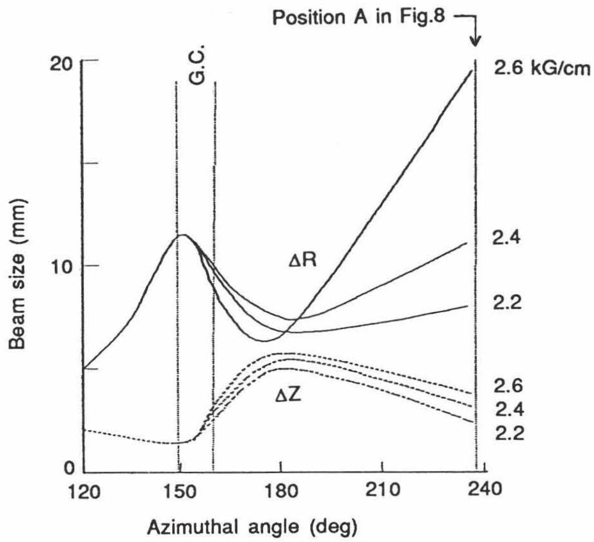

Fig.10. Dependence of the beam sizes in the horizontal (ΔR) and the vertical (ΔZ) directions on the strength of field gradient of the gradient corrector for the 7 MeV/u $^{14}N^{5+}$ ions.

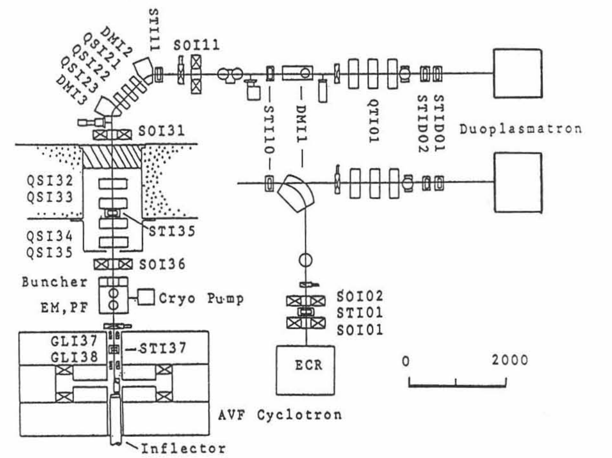

Fig.11. Schematic drawing of the injection beam line from the ion sources to the AVF cyclotron.

5. INJECTION AND EXTRACTION BEAM LINES

Figure 11 shows the layout of the injector beam transport line from ion sources such as an ECR source and a duoplasmatron to the AVF cyclotron. A heavy ion beam from the ECR source is focused at a collimating slit by double solenoids SOI01 and SOI02. The charge and mass of the ion are analyzed with a double focusing 90° bending magnet DMI1. The momentum resolving power of the system is calculated to be 20, if the beam size at the collimating slit is 20mm in full width. This beam size corresponds to the beam emittance of 200π mm.mrad. A system consisting of two 45° bending magnets and three quadrupole singlets DMI2~DMI3 constitutes an achromatic one and bends the 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 steerer are set inside the hole of the upper yoke. A proton or deutoron beam from the duoplasmatron source is focused by a quadrupole triplet QTI01 at the analyzing slit for heavy ions. A 45° bending magnet DMI2 has a dispersion enough to separate the atomic ion from molecular ions.

The layout of the extraction beam transport line from the AVF cyclotron to RRC is shown in Fig.12. A beam extracted from the cyclotron is focused by a quadrupole triplet QTC01 at a point 2m downstream which is a source point for the succeeding beam transport system. A charge stripper is installed at the point. A section consisting of two quadupole doublets QDC02 and QDC21 and a 90° bending magnet DMC2 is a charge and momentum analyzing system with a dispersion of 6 m. The beam is achromatized after passing through a quadrupole doublet QDC22 and a dipole magnet DMS3. A 90° bending magnet DMC1 is prepared to bend down a beam and deliver it directly to the experimental room for material physics.

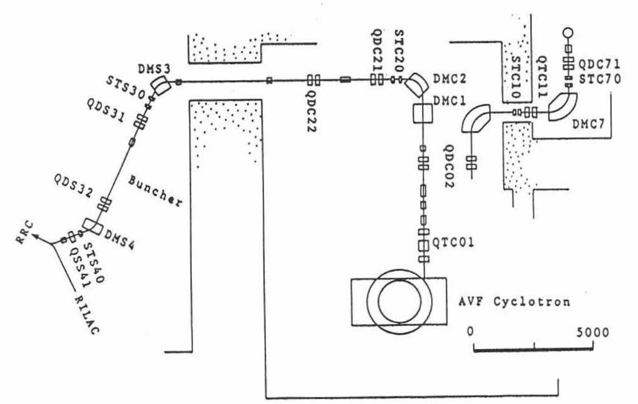

Fig.12. Schematic drawing of the extraction beam line from the AVF cyclotron to RRC.

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