H- Beam Acceleration Test and Extraction Orbit Study at the CYRIC 680-Cyclotron

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Introduction

As a part of development programs at the CYRIC 680 AVF cyclotron, we have been studying high-current proton extraction with H^- beam acceleration in the cyclotron. Advantage of this method is the simplicity of extraction; it is achieved by passing the accelerated H^- ion though an appropriately positioned thin foil to strip off the electrons. The charge-exchanged H^+ ion is then deflected out into a suitable exit channel. A shematic drawing of the extraction process is illustrated in Fig. 1.

The first trial of H^- beam acceleration test in the cyclotron was performed in August 1992. Two kinds of acceleration modes with harmonic number 2 and 3 were successfully tested. The cyclotron parameters in the both acceleration modes corresponded to the proton energies of 15 and 35 MeV, respectively. Then the polarities of the magnetic fields excitation for the main, trim and harmonic coils were changed. The test is still continued on the cyclotron. At the same time the extraction orbit study has been carried out.

In this report the performance results of the H^- beam acceleration test and some results of calculation of the extraction orbit properties are discussed.

H^- beam acceleration test

In the first trial of the H^-beam acceleration the hot-filament type PIG ion source, which is usualy used for the acceleration of positive light ions, was used. About 2 μA H^- beam intensity at the point of half turn in the central region was obtained with the arc voltage and arc current of the ion source of 250 V and 0.7 mA, respectiverly. After this some developmental works, e.g. using various kinds of slit aperture of the ion source exit, have been done to improve the beam intensity by using the same ion source. The experimental results of the beam intensities with four different slit apertures are shown in Fig.2. As can be seen in Fig.2 the maximum beam intensity of about 5.5 μA at the probe radius of R=63 cm

was obtained with the slit aperture of 0.5 mm wide and 6 mm hight. In this case the transmisiion ratio from R=15 cm to R=63 cm was observed to be about 50 percent at the vacuum pressure of 5×10^{-6} Torr. This clearly indicates that the vacuum pressure in the cyclotron is not sufficiently low enough to avoid beam losses during acceleration.

Extraction orbit study

The numerical integration of the differential equations of the ion orbits were performed with the measured magnetic fields $B_z(r, \theta, 0)$ of the cyclotron. To calculate the field compornents $B_r(r, \theta, 0)$, $B_\theta(r, \theta, 0)$ and $B_z(r, \theta, 0)$ in a cylindrical coordinate system, using the Taylar expansion method near the median plane was used as ;

$$B_r(r, \theta, z) = z \frac{\partial B_z}{\partial r} (r, \theta, 0)$$

$$B_\theta(r, \theta, z) = \frac{z}{r} \frac{\partial B_z}{\partial r} (r, \theta, 0)$$

$$B_z(r, \theta, z) = B_z(r, \theta, 0) - \frac{1}{2} z^2 \left[\frac{\partial B_z}{\partial r^2}(r, \theta, 0) + \frac{1}{r} \frac{\partial B_z}{\partial r}(r, \theta, 0) + \frac{1}{r^2} \frac{\partial B_z}{\partial \theta^2}(r, \theta, 0) \right]. \quad (1)$$

In calculating the extraction orbit, the starting position where the electron stripping foil is placed was selected under the criterion of the desirable extraction orbit in the cyclotron. The radial position of this point was determined by a recent H^- beam acceleration test to be the maximum radius of 63 cm, that is, just before the beam hitting the existing deflector system used for normal beam extraction. To find the optimum azimuthal position, we tried the orbit calculation over and over again with the parameters of the equiliblium orbit taken into consideration. The result of the adopted foil position is shown in Fig.3, together with a single-ion orbit. Horizontal and vertical amplitudes of the ion orbits were also calculated relative to the reference orbit. The calculated ion trajectories are ploted in Fig.4. They behaved similally as in a field free space, becouse the ions pass through almost perpendicularlly to the steep decrease of the magnetic equipotential line in the fring field. Other details are given in the figure. The effect of the electromagnetic stripping of H^- beam due to Lorentz force is negligibly small in this case becouse of the maximum energy of 40 MeV in due to small ion velocity for Lorentz force.

Outlook

In view of the successful results of the H^- beam acceleration test and the calculation results of the extraction orbit, as described above, the program may possibly be realized. For the future, our effort will be extended to the improvement of the cyclotron vacuum pressure to

avoid the beam losses due to stripping by the residual gas and to the developement of a high current H^- ion source giving a beam of a few hundred μA range at the cyclotron exit.

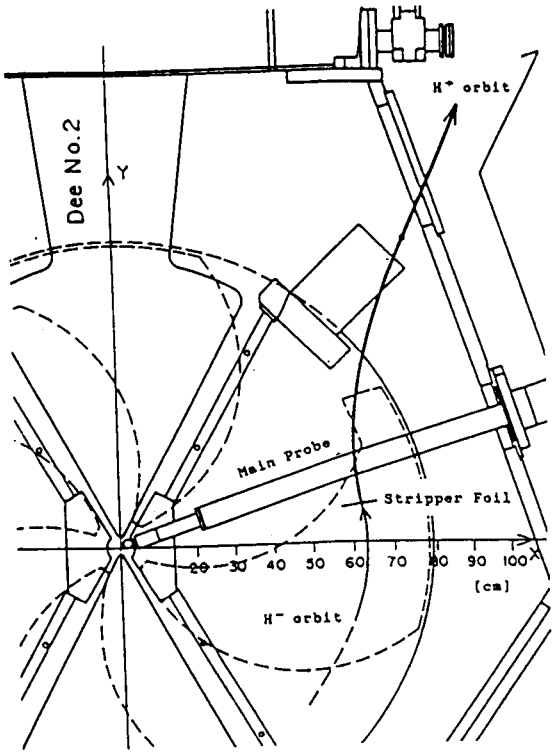

Fig. 1. Schematic drawing of the beam extraction.

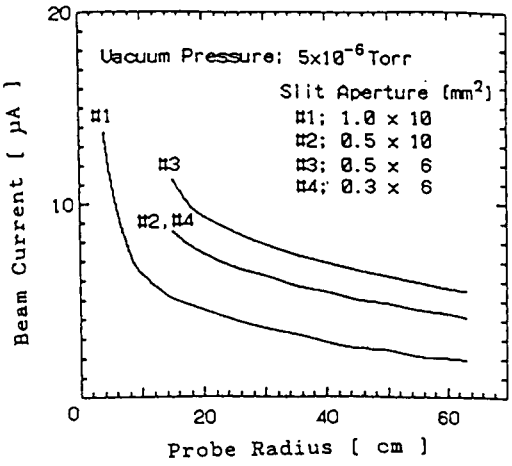

Fig. 2. The H^- beam intensity measured as a function of the probe radius with four different slit apertures of the ion source exit (acceleration of H^- ion up to 21 MeV).

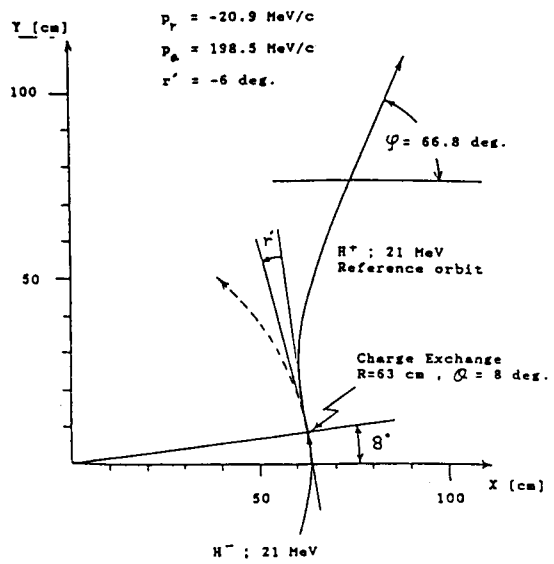

Fig. 3. The optimum radial and azimuthal position of the electron stripping foil for a desirable extraction orbit in the cyclotron ; the orbits for the H ion as well as the H ion of 21 MeV are shown.

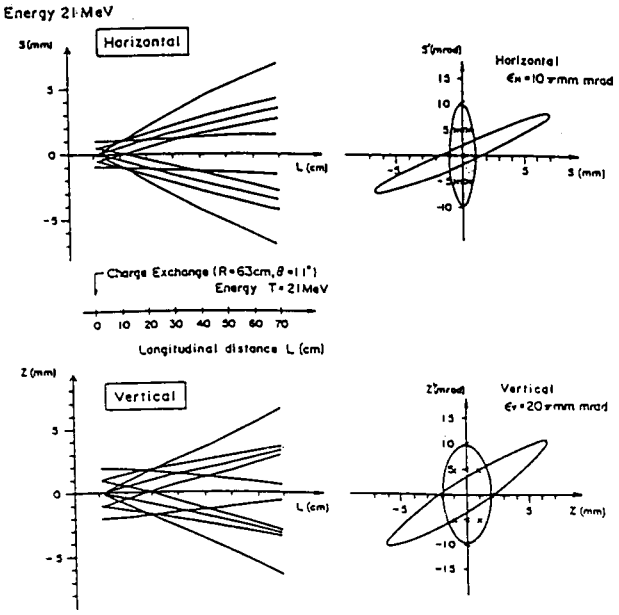

Fig. 4. The calculated trajectories of H ion of 21 MeV in the horizontal and vertical planes with different initial condition contained in the each phase spaces as a function of the longitudinal distance from the stripping foil.