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A Study on Extraction System in KIRAMS-13 Cyclotron

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Abstract

The optimization of the stripping extraction system in the KIRAMS-13 cyclotron has been achieved by determination of the position and the thickness of the carbon foil and the design of the structure of the beam transport line. First we calculated the proper thickness of the stripping carbon foil using the charge exchange process with the theoretical electron loss cross sections. To consider the additional increase of a carbon foil lifetime, we determined the foil position where the beam size is large enough to spread the beam about half of the axial maximum amplitude and the stripped beam is weakly focused. In order to configure a beam transport line and study the beam emittances, the beam trajectories after stripping have been calculated with the conventional beam tracking method. From this work the optimized position of the stripping carbon foil and the structure of beam transport line to the target system have been constructed in the KIRAMS-13 cyclotron.

1. Introduction

Recently, according to a rapidly increasing demand for a cancer diagnosis using positron emission radioisotope such as ^{18}F, the cyclotron producing the radioisotope has come into wide use. The KIRAMS-13 cyclotron for position emission tomography (PET) had been developed by Korea Institute of Radiological and Medical Sciences (KIRAMS) several years ago. In order to increase its efficiency, we modified the magnet system for power, the internal PIG ion source and the central region for beam currents, the stripping extraction system for extraction efficiency.

KIRAMS-13 cyclotron accelerates negative hydrogen ions generated from the internal PIG ion source. By using the stripping carbon foil, 13 MeV protons are extracted from the cyclotron. The optimization of the stripping extraction system can be achieved by determination of the position and the thickness of the carbon foil and the design of the beam transport line after extraction.

This paper is devoted to study the optimization of the stripping extraction system in KIRAMS-13 cyclotron.

2. The thickness of the Carbon foil

The thickness of the Carbon foil plays an important role in high beam transmission, high charge stripping effect, and long lifetime for the irradiation of beam in an accelerator. For higher transmission of light ions such as hydrogen, stripping foils are required to have certain thickness for the sake of attaining charge equilibration. If the thicker foils than this certain thickness are used, the lifetime is decreased faster by the heat generated during the irradiation. In order to maximize the lifetime of stripping foils, we should investigate the thickness for the charge exchange process.

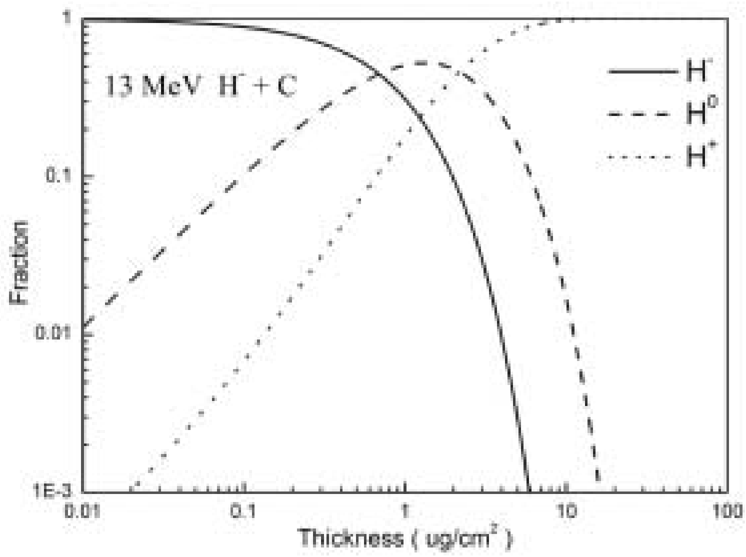

Fig. 1 Calculated charge fractions of hydrogens

The fraction f_o ions, F_q, with charge state q, at the penetration depth x in matter is given by the following rate equation:

$$\frac{dF_q(x)}{dx} = \sum_k (F_k \sigma_{kq} - F_q \sigma_{qk}) \qquad (1)$$

where σ_{kq} stands for the charge exchange cross-section of ions from charge state k to q. We apply the Eq. (1) to the incidence of H^- ions colliding with a carbon stripper. Firstly, the multiple electron transfer, σ_{kq} (|k-q|>1) is negligible because the collision is dominated with distant collision. Secondly, for the collision of H + C with projectile energy greater than 1 MeV, the electron capture process of hydrogen, σ_{kq} (k>q), is negligible compared the the electron loss process σ_{kq} (k<q). Therefore, the solution of Eq. (1) is written as

$$F_{-1}(x) = \exp\left(-\sigma_{-10}\right)$$

$$F_0(x) = \frac{\sigma_{-10}}{\sigma_{-10} - \sigma_{01}}[\exp(-\sigma_{01}x) - \exp(-\sigma_{-10}x)]$$

$$F_1(x) = 1 - F_{-1}(x) - F_0(x) \qquad (2)$$

Calculated values of F_q of hydrogen for the cases of 13 MeV H^- + C are drawn in Fig. 1, where the theoretical electron loss cross sections by Gillespie [1,2] are adopted. Figure 1 indicates that the thickness of carbon foil for the attainment of charge equilibration is about 11 μg/cm^2 for the incident 13 MeV H- ions. Now an amorphous carbon foil of 50 μg/cm^2 which is the least thickness on sale has been used for KIRAMS-13 cyclotron.

3. The position of the carbon foil

This KIRAMS-13 cyclotron produces ^{18}F with irradiating protons into ^{18}O water target. In the view of target cooling, the beam size at the target should be spread as wide as that of the target foil window. Our target system has the window 16 mm wide, and the quadrant between the stripping foil and target foil 15 mm wide. When the proton beam applies to the target water, the water level become lower due to the boiling. Therefore the best beam shape at the target is wide about 15 mm and has some band in the vertical direction so that the beam should be focused after stripping in the vertical direction.

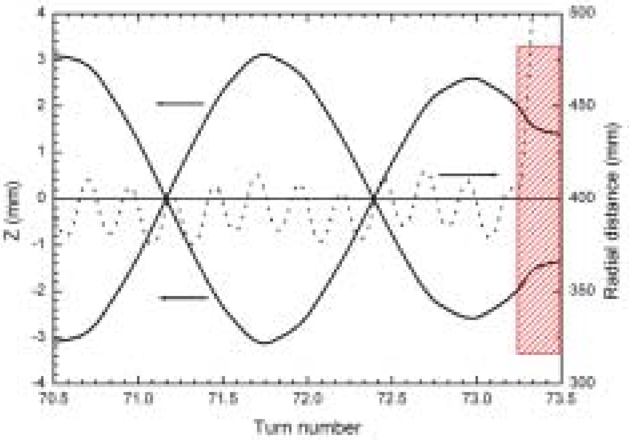

Fig. 2 Vertical motion and radial distance from the cyclotron center. The inner rectangular box represents the region after stripping.

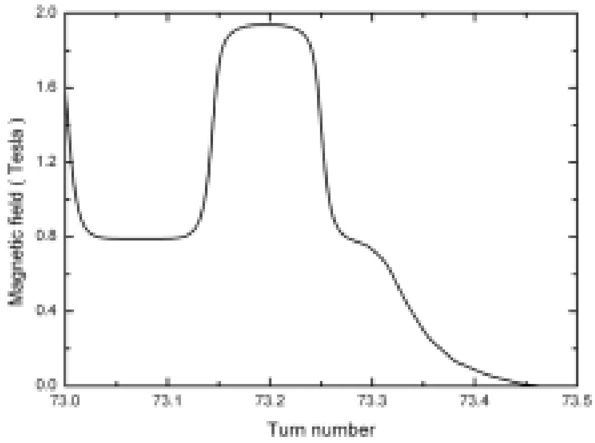

Fig. 3 The magnetic field around the carbon foil and after stripping

The conventional beam tracking code has been used to calculate the beam status around the extraction system. The magnetic field within 0.46 meter has been measured and the magnetic field above the 0.46 meter has been calculated by OPERA3D. The 3D electric field map has been obtained from the well-known RELAX3D [3]. The beam trajectory calculated from the central region in the KIRAMS13 cyclotron. The representative starting particles have the initial RF phase of 310 degree and for the calculation of vertical motion trajectory the traces at the puller and the copper tape are used. As a result of the calculation the best position of the carbon foil is (397mm, 57^{o}). 57^{o} is the angle from the Dee center axis. The vertical width is about 3 mm at the foil and the vertical motion of the stripped beam is weakly focused.

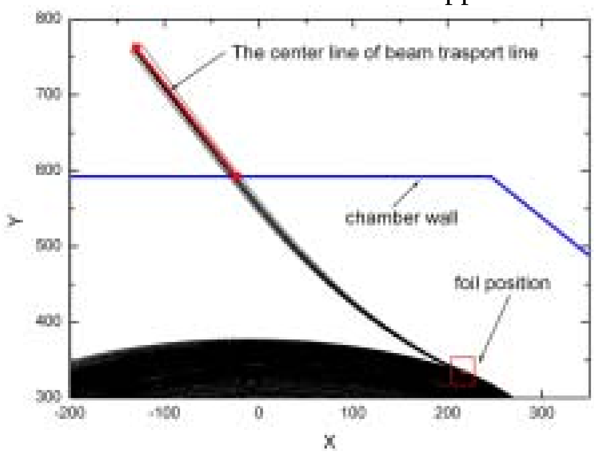

Fig. 4 Beam trajectories in horizontal motion

4. The design of a beam transport line for extraction

The radial motion of the stripped beam calculated with the conventional beam trajectory code [4,5]. All the initial parameter is the same as the calculation at the vertical motion except the starting initial z=0. Figure 4 represents the results of the beam trajectories. The range of initial RF phase is from 290 to 330 and the initial angular range with respect to the direction of slit face is from -15 deg to 15 deg. The horizontal width of the stripped beam at the target position of 200 mm apart from the chamber wall is about 16 mm. The angle of beam transport line from the direction of chamber wall is about 31 deg.

5. Conclusions

The stripping extraction system of KIRAMS-13 cyclotron has been investigated. The optimal carbon foil thickness is calculated about 12 μg/cm^2. The best foil position in view of the vertical beam size and the focusing of stripped beam is 397 mm from the cyclotron center and 57 degree from the axis of Dees. The angle of the beam transport line from the chamber wall is about 31 degree, and the horizontal beam size at the target 200 mm apart from the chamber wall is about the the 16 mm.

6. References

[1] G. H. Gillespie,"High-energy cross section for H- ions incident on intermediate and high-Z atoms", *Physical Review A* **16** 943 (1977)

[2] G. H. Gillespie,"Excitation and ionization contributions to sum-rule Born cross sections for collisions of one-electron ions with atoms", *Physical Review A* **18** 1967 (1978)

[3] H. Houtman and C. Kost, *Proc. Of the Europhysics Conference, Computing in Accelerator Design and Operations, Lect. Notes in Physics 215* (Springer Verlag, Berlin, 1983) pp. 93-103

[4] J. L. Ristic-Djurovic., "Stripping extraction of positive ions from a cyclotron", *Physical Review Special Topics – Accelerators and Beams* **4** 123501 (2001)

[5] S. S. Tomic and E. V. Samsonov, "Analytical description of stripping foil extraction from isochronous cyclotrons", *Physical Review E* **65** 036504 (2002)