STUDY OF BEAM EXTRACTION FROM THE UNIVERSITY OF MANITOBA CYCLOTRON

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Abstract

Computer simulated extraction studies of beam from the University of Manitoba cyclotron were carried out, based on a recently mapped magnetic field.

Introduction

In the University of Manitoba cyclotron, variable energy proton and deuteron are obtained by first accelerating H^- and D^- ions and then stripping the two electrons from the ions by a thin aluminum foil placed in the cyclotron circulating current. This stripping results in a sudden reversal of the curvature of radius of ions. A combination magnet, which is located 1.5 m away from the center of the cyclotron, bends the trajectories into the common beam transport system.

Recently the cyclotron underwent an extensive upgrading which included reshaping of the magnetic field of the cyclotron. The reshaping resulted in a change in the extraction beam trajectory and therefore beam can no longer be extracted by placing the stripping foil according to the old data. As a temporary measure, the position has been empirically adjusted for extraction. For a maximum exploitation of the upgraded beam, however, it is obviously desirable to carry out an appropriate beam extraction study. Such a study has, in fact, been carried out and is described in the following paragraphs.

Description

The starting point is the computation of equilibrium orbits inside the cyclotron as a function of energy of the accelerated H^- ions. The equilibrium orbits were computed from a computer code MAPANAL which reads the mapped cyclotron magnetic field and then traces the particle to find the equilibrium orbit. Fig. 1 shows three equilibrium orbits, corresponding to the 20 (the lowest energy particle that is extractable), 35 and 50 MeV (the highest energy particle that is extractable) H^- ions.

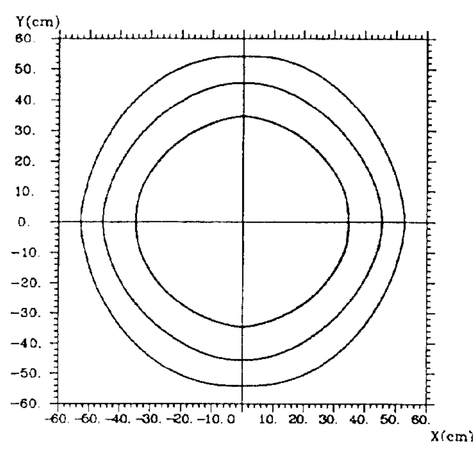

Fig. 1. H^- equilibrium orbits for three selected energies 20, 35 and 50 MeV.

A stripping foil is then supposed to be placed at a position inside the cyclotron which will intercept some of the equilibrium orbits. Another computer code, EXTBEAM, was written to trace the orbits of the intercepted H^- ions which convert to H^+ at the point of interception. The code, EXTBEAM, traces the particles all the way through the cyclotron field (including the fringe field) and the field of the combination magnet. The condition for extraction is that the reference particle has to enter the combination magnet at 90° and that, on leaving the combination magnet the trajectory has to be on-axis along the beam transport line. This is a successive approach to find the optimum position (radial and angular) of the stripping foil. Table 1 shows the parameters (including the position of the stripping foil) for three ion energies obtained, and fig. 2 shows the corresponding extraction trajectories.

Table 1. Extraction Parameters

Beam Energy (MeV)	20	35	50
Radius of the Stripping Foil (cm)	34.6	45.4	52.8
Azimuth of the Stripping Foil	17.4°	1.4°	0.4°
Needed C.M.* Field to Bend Beam (kG)	-8.1	-2.1	+2.3
Deflected Angle of the Beam at C.M.	17.0°	3.0°	-3.4°

*C.M. is an abbreviation for Combination Magnet

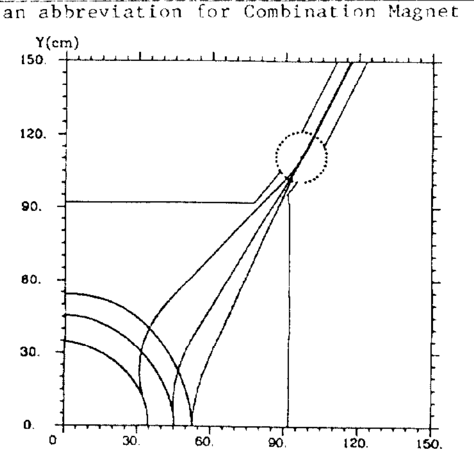

Fig. 2. H^+ extraction reference orbits for the three energies 20, 35 and 50 MeV.

It is noted from the table that the radial and azimuthal positions of the stripping foil have to be varied between 34 and 53 cm and 18 and 0 degrees respectively to accommodate particles between 20 and 50 MeV. To study the properties of the extracted beam, an assumption was made that the beam has a circular center

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spread of r = +-1.5 mm (see fig. 3), that the beam is on-center at the cyclotron's geometrical center (i.e., the reference particle follows the equilibrium orbit) at the extraction radius and that the particle gain energy of 80 keV per turn near the extraction radius. The stripping foil is assumed to have a sufficiently wide radial width and zero thickness. A further assumption was made that the radial and axial motion can be decoupled. With this assumption, it was possible to study the radial and axial motion separately.

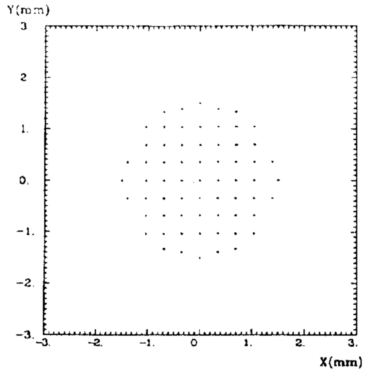
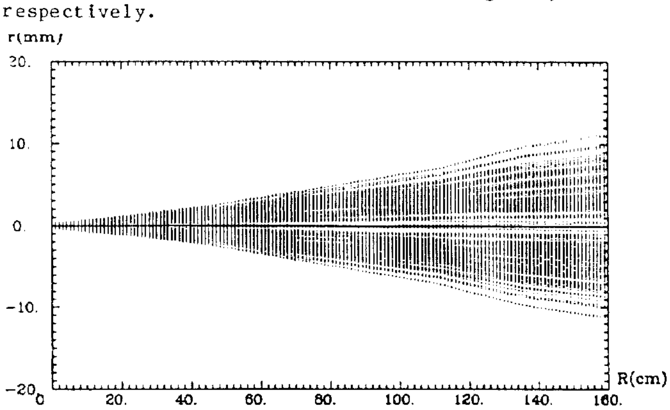
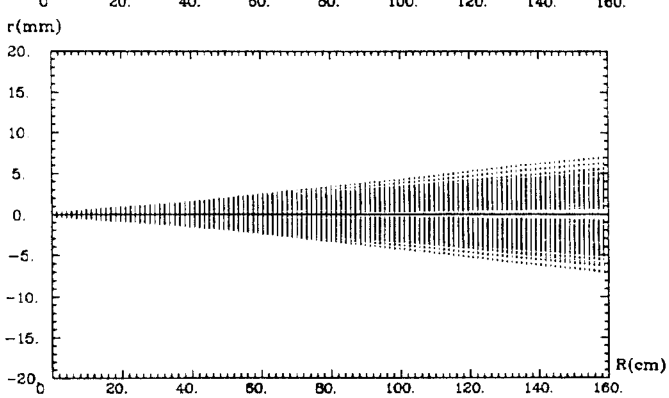
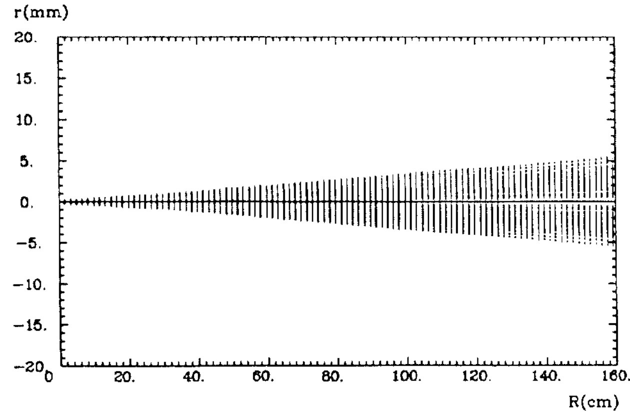


Fig. 3. Assumed center distribution of the extracted beam.

For the study of the radial motion, a set of particles having orbit centers (in the sense of average over one complete turn) located as is shown in fig. 3 was chosen. The beam's center spread in the radial direction towards the stripping foil induces energy spread in the extracted beam while the center spread in the direction perpendicular to the above is responsible for the divergence of the extracted beam. In addition, the increment of 80 keV per turn of the beam energy from acceleration induces an additional energy spread and radial spread. The results for the three selected extraction energies are shown in figs. 4, 5 and 6 respectively.







Figs. 4-6. Radial spread of H^+ extracted beam. The corresponding energies are 4-- (20±0.201) MeV; 5--(35±0.254) MeV; 6-- (50±0.298) MeV.

It is seen that the radial beam width is as large as 23 mm at 160 cm down stream (about 30 cm further down stream of the combination magnet). The size reduces to 15 mm for a 35 MeV beam, and to 11 mm for a 50 MeV beam. The effective beam phase space area has been calculated with the program EXTBEAM. They are 23, 11, and 9 mm mrad respectively at this position. A direct observation of beam at this point has not been possible, but inferred from beam spot size further down stream (a fluorescent screen is placed after the beam is focused by a pair of magnetic lenses). Both are in agreement. The beam energy spread can also be deduced. The values obtained are 403, 508 and 595 keV respectively. These compared with our observed energy spread of 500 keV FWHH at 40 MeV.

The axial motion was also investigated. Figs. 7-8. shows the case for a 35 MeV beam.

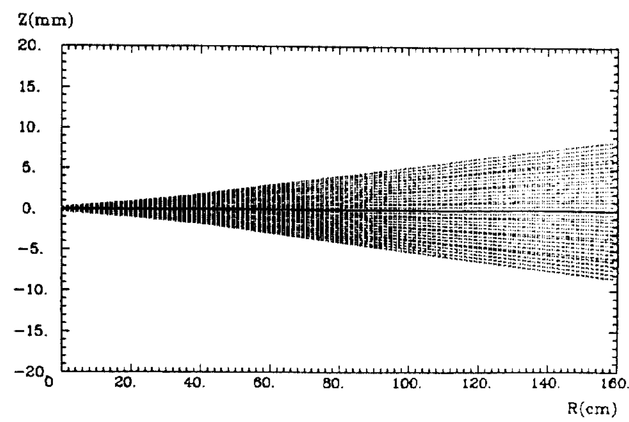


Fig. 7. Vertical spread of H^+ extracted beam (35 ± 0.254 MeV).

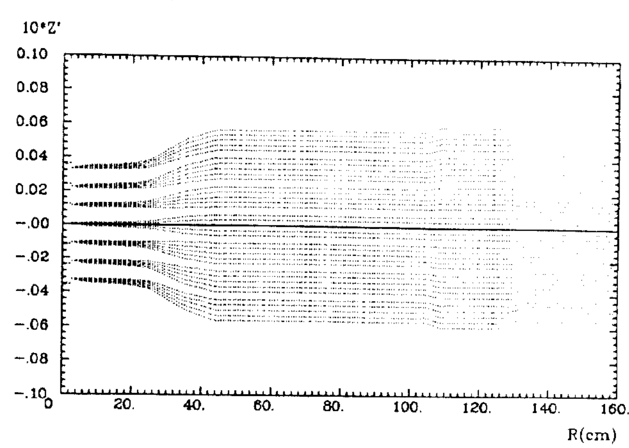


Fig. 8. Vertical slope trace of the extracted beam (35 MeV).

The vertical size is seen to be 17 mm and diverging. The study for the other two energies indicates that the size of the beam at the end point are approximately the same, although the divergence is the smallest for the 20 MeV beam, and the largest for the 50 MeV beam.

A more detailed study will be published elsewhere in the near future.

References

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