Extraction of multiple beams of various energies from the TRIUMF negative ion isochronous cyclotron

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ABSTRACT

Acceleration of negative ions in the TRIUMF accelerator permits extraction of up to six proton beams, each beam independently variable in energy from 150 MeV to 500 MeV. The position of the foil which strips the electrons from the accelerated H^- ions can be chosen so that the extraction trajectories of the various energies intersect at a common cross-over point outside the accelerator. Calculations show that thin stripping foils can be designed to handle beam powers equivalent to at least 100 μA of 500 MeV protons. A combination magnet placed at the cross-over point directs these beams into a transport system which is designed to be achromatic between the stripping foil and the entrance to the experimental area.

Field measurements on the 1/20 scale model accelerator magnet have been used to determine the optical properties of the extracted beams passing through the fringe field. Stripping foil positions as a function of energy, and transfer matrices for these trajectories have been calculated for a number of postions of the cross-over point for the two directions of motion of the ions in the accelerator. The components of the transfer matrix vary little with position of the cross-over point. For the case that the direction of the orbits in the accelerator is opposite to the pole spiral, there is a smaller variation in the matrix elements with extracted beam energy.

1. INTRODUCTION

One attribute of the negative ion isochronous cyclotron is the ease with which the particles accelerated in the machine may be extracted by stripping the electrons from the ions, thus reversing the sign of the radius of curvature.[1]

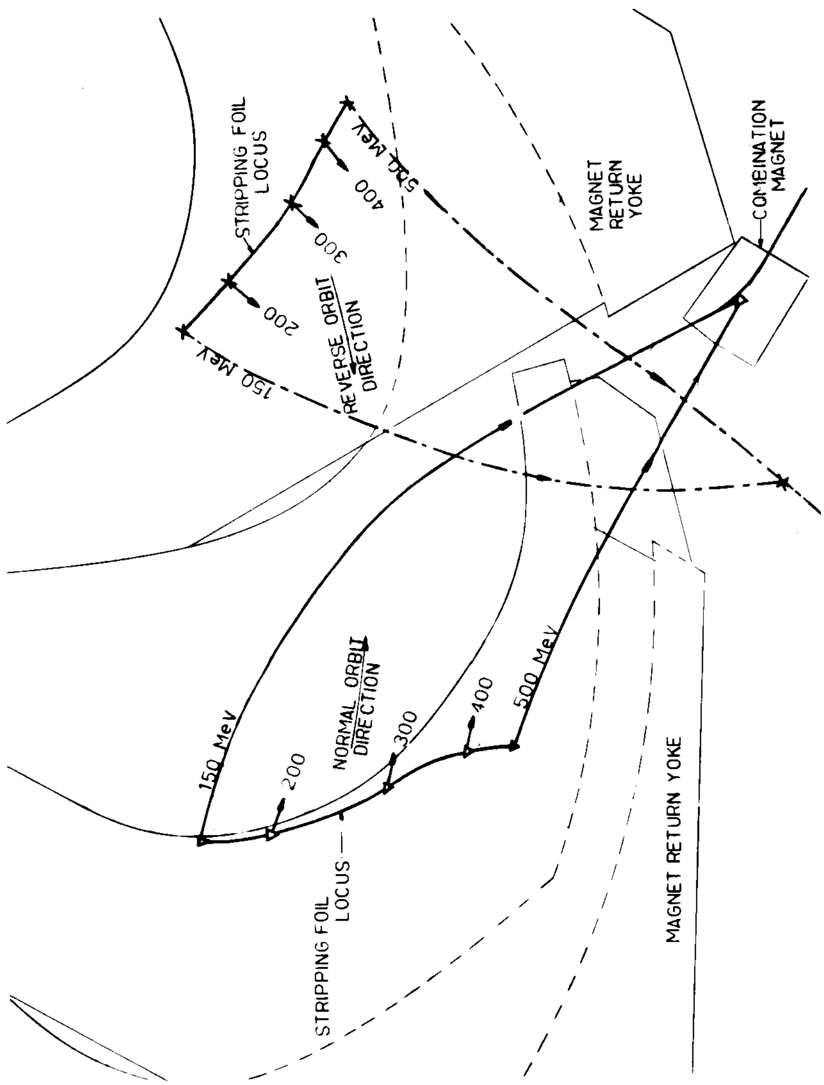

Fig. 1. Stripping foil loci and extraction trajectories for ions accelerated in the normal direction (Δ) and reverse direction (x)

The energy of the extracted beam can be varied easily by adjusting the radial position of the stripping foil. By suitable choice of the azimuthal position of the foil, the extracted orbits at each energy can be made to cross at a common point, the cross-over point, outside the accelerator. A bending magnet, known as the combination magnet, placed at the cross-over point can then be used to direct the beams along one beam line to the experimental area. Because of the 6-fold symmetry of the TRIUMF cyclotron, up to six separate beams may be extracted through the gaps in the return yoke of the magnet. Calculations indicate that four of these beams should be independently variable in energy over a range from 150 MeV to 500 MeV, while the remaining two extracted beams will have a restricted energy range because of the interference with the resonator structure. A fraction of the circulating beam can be intercepted at any one of the foil positions permitting the remaining beam to be accelerated to higher energies and extracted at other extraction

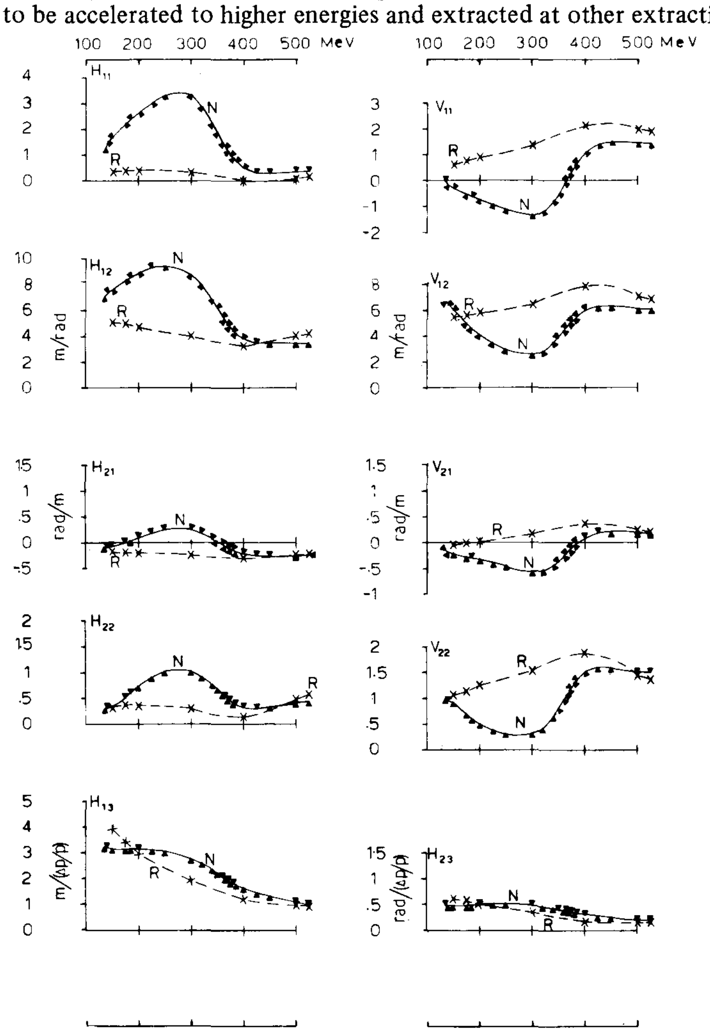

Fig. 2. Transfer matrix elements in the horizontal (H_{ij}) and vertical (V_{ij}) planes as a function of energy for ions accelerated in the normal direction (Δ) and reverse direction (x)

positions. Thus it is possible to extract up to six separate beams independently variable in energy and intensity.

2. TRAJECTORY CALCULATIONS

A trajectory tracking computer program was used to determine the position of the stripping foil as a function of energy for which the trajectories would have a common cross-over point. The magnetic field data used in the computation was measured on the 1/20 scale model of the accelerator magnet.[2] Since the ions may be accelerated in either direction with respect to the sense of the spiral of the poles, extraction trajectories were determined for the ions orbiting in the same sense as the spiral, called the normal direction, and in the revərse direction. The stripping foil loci and the extracted trajectories for 150 MeV and 500 MeV are plotted in Fig. 1 for the normal and reverse directions for two representative cross-over points. The combination magnet centred at the cross-over point necessary to deflect the 150 MeV trajectory along the 500 MeV trajectory must be stronger for the reverse sense; the angle being 45·8° as opposed to 32·6° for the normal sense. The normal orbit direction has been chosen because there are more extracted beams which can be used over the full energy range.

3. ION OPTICAL PROPERTIES OF THE EXTRACTED BEAMS

The ion optical transfer matrices between the stripping foil and the cross-over point were calculated for each extraction trajectory by tracking a sine-like, a cosine-like and a dispersion trajectory. The components for the horizontal (H_{ij}) and vertical (V_{ij}) transfer matrices for the two groups of trajectories shown in Fig. 1 are plotted in Fig. 2 as a function of energy.

The extraction matrix elements for the normal orbit direction show a much larger variation with energy than the reverse direction. This is especially noticeable for the trajectories between 300 and 400 MeV for which the gradient of the field normal to the trajectory is larger along the hill-valley interface. Studies have shown[3,4] that beam transport systems can be designed which can compensate for the dispersion effects of the fringe field at each energy between 150 and 500 MeV, producing an achromatic transport system between the stripping foil and the experimental area. The inclusion of second and third order terms in the field expansion and the equations of motion showed that these non-linear terms had a very small effect on the trajectories for the extracted beam emittances expected and can be neglected.

4. STRIPPING FOILS

Stripping foils placed in the circulating beam to remove the two electrons from the H^- ions will absorb energy from the beam due to ionisation loss by the protons, which will be small, and from the energy of the two stripped electrons which, because of the small radius of curvature, will all be deposited in the foil. This latter contributes 0·5 W per μA of extracted beam. The stripping foil should be thin to reduce the degradation of the extracted beam due to energy loss straggle and multiple coulomb scattering, but thick enough to give a reasonable lifetime allowing for the evaporation of material from the surface. Estimates have been made that 4 mg/cm^2 of carbon can be used as a stripping foil which will permit a beam of greater than 100 μA to be extracted when the heat is dissipated by radiation.

5. COMBINATION MAGNET DESIGN

The combination magnet will be a uniform field bending magnet excited to accommodate the required beam energy, low field values being used for 500 MeV beams. Rectangular magnets and magnets with pole profiles to give normal entrance for all energies have been considered. The vertical focusing effects of the former design appear to be useful for the achromatic extraction conditions required at all the energies.[4]

REFERENCES

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