PARTIAL BEAM EXTRACTION SCHEME OF NEGATIVE HYDROGEN ION*

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Abstract

A new scheme for beam extraction is presented to partially extract a negative hydrogen ion beam at 260 MeV from the main linac where both protons and negative hydrogen ions are accelerated up to 1 GeV. The negative hydrogen ions are extracted by a stripper magnet and the un-extracted ions are returned to the linac. The main feature of this extractor is its ability to regulate the intensity of the extracted beam with the stripper magnet. This extraction scheme will be utilized for the KOMAC (Korea Multi-purpose Accelerator Complex) linear accelerator of 1 GeV cw proton (H^+)/negative-hydrogen (H^-) beams with an intensity of 20 mA.

1 INTRODUCTION

Korea Atomic Energy Research Institute (KAERI) is proposing to develop a 20 MW (1 GeV and 20 mA) cw H^+/H^- linear accelerator (Fig. 1) under the KOMAC [1] (Korea Multi-purpose Accelerator Complex) project. The KOMAC linac will accelerate both H^+ and H^- up to 1 GeV while partially extracting H^- at 100 and 260 MeV. Since the accelerator is to be utilized multi-purposely, regulating the beam intensity is a crucial requirement for the beam extraction system. The extraction method developed in this study is to use a stripper magnet for magnet stripping [2] which removes the weakly bound electron from H^-. The 260 MeV H^- beam extractor design is the main objective of this study, where the beam can be used for deep-sited tumor therapy.

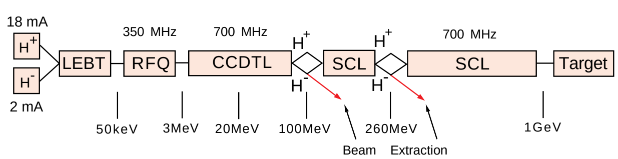

Figure 1: Schematic layout of the KOMAC linac.

2 MAGNET DESIGN

Since we need to extract H^- at the desired intensity, a new stripper magnet is needed. The design requirements for the stripper magnet are (1) minimizing the emittance growth of the extracted beam, (2) minimizing the centroid-shift of the extracted beam in angle, (3) decoupling the H^- bending from the stripping process, and (4) maximizing the angle between the extracted beam direction and the un-extracted H^- beam direction. The first requirement is very important since there is an emittance limit for a given vacuum pipe dimension. The second requirement is due to the fact that if the H^- beam is extracted at a different horizontal angle for a given intensity, the downstream beamline has to transport all the extracted beams with different centroid angles. The third requirement is also important since the un-extracted H^- beam must be returned to the main linac. The last requirement is important because the beamline element for the extracted beam must be placed as close as possible for focusing. Fig. 2 shows the design of the stripper magnet using POISSON [3]. The stripper magnet consists of super-

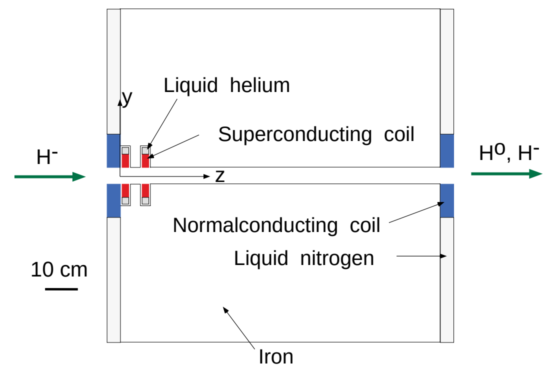

Figure 2: Stripper Magnet

conducting and normalconducting coils. When H^- travels through this stripper, it first encounters the field generated by the superconducting coils. If the field is higher than the threshold field ($\simeq 0.97$ T), then it has a significant probability for losing an electron and becoming an H°. By varying the current in the superconducting coil, the intensity of the extracted beam can be regulated as shown in Fig. 3. The

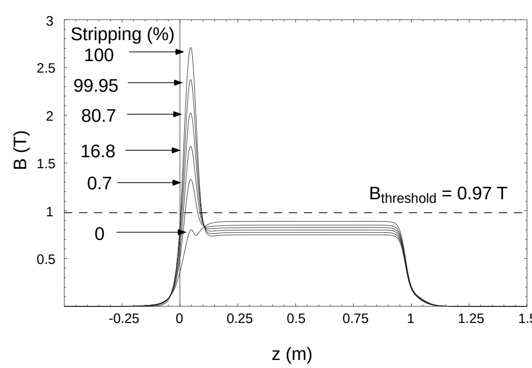

Figure 3: Stripper magnetic field at the mid-plane (y = 0).

cross-sectional area of the coil is 2 cm $\times$ 4 cm and the current density changes from 0 to 165 A/mm^2. The magnet gap is 5 cm. The stripping region is less than 7 cm along the beam direction, and the angle between the extracted

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beam centroid and the initial beam direction is about 30 mr. The surviving H^- must be returned to the linac, and initially the normalconducting current is adjusted so that $\int Bdl/B_\rho$ is fixed at 20°, where B is the vertical field and B_ρ (= 2.487 T-m) is the beam rigidity. The cross-section of the coil is 4 cm $\times$ 10 cm and the maximum current density is 4.4 A/mm^2.

3 SIMULATION

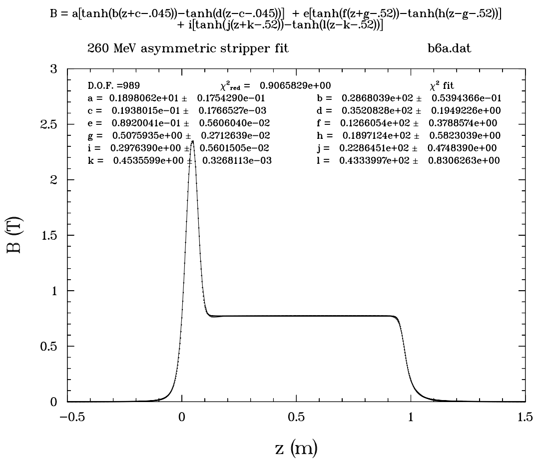

Figure 4: Mid-plane B_y field fitting.

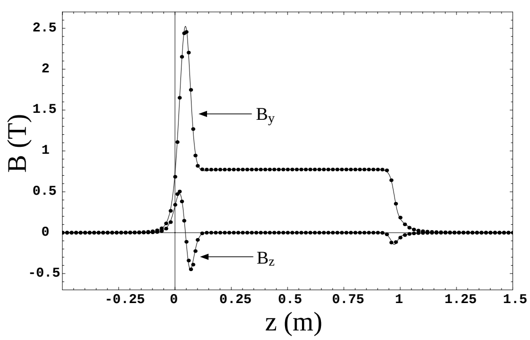

Figure 5: Off-mid-plane field at y = 1 cm.

After the POISSON run is finished with given currents in the superconducting and normalconducting coils, the field at the mid-plane is fitted with a sum of six $\tanh$ functions. Fig. 4 shows that the field is described analytically with a fitting function of 12 parameters. The off-mid-plane field which interacts with H^- sitting at some distance from the mid-plane could be computed from the mid-plane field as

$$\begin{aligned} B_y(y,z) &= \mathrm{Re}[B_y(0, z+iy)], \\ B_z(y,z) &= \mathrm{Im}[B_y(0, z+iy)], \end{aligned} \qquad (1)$$

and Fig. 5 shows the field data (solid circle) which is obtained from POISSON at a vertical distance of 1 cm from the mid-plane. The field (solid curve) computed from the mid-plane field matches well with the data points. Tracking H^- through the stripper magnet is done by solving a first order differential equation. The DIVPAG subroutine from IMSL MATH/LIBRARY was used to obtain results with an accumulated error of 10^{-10}. The stripping process is also simulated using the life time given in the reference [2].

4 BEAM EXTRACTOR DESIGN

The beam extractor design is shown in Fig. 6. It consists of a stripper magnet, 5 dipoles (BM), 12 quadrupoles (QM), and 4 steering magnets (SM). The dipole bends the

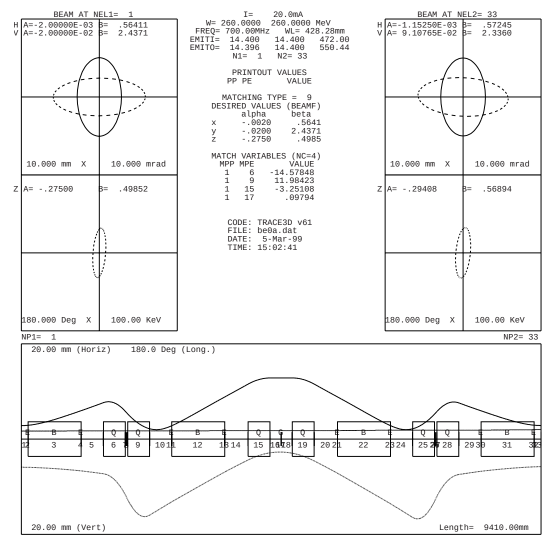

Figure 7: H^+ beamline setup (TRACE 3-D[4]).

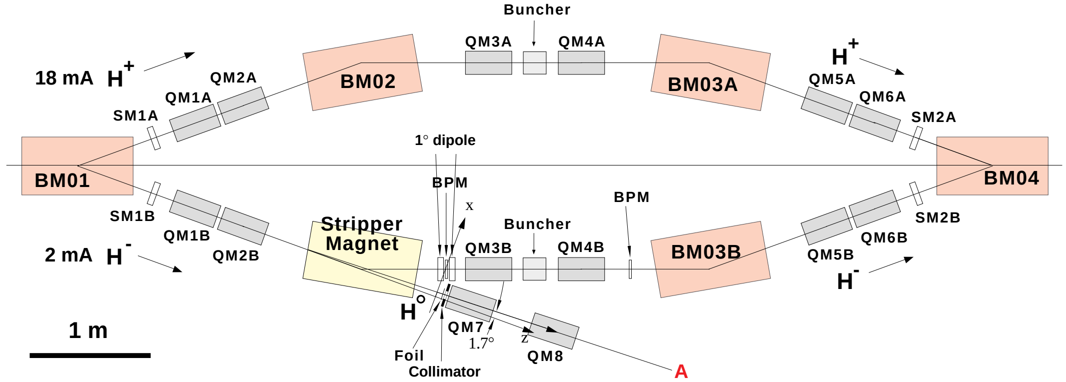

Figure 6: 260 MeV H^- beam extractor layout.

H^- (or H^+) beam by 20° with 0.904 T magnetic field. The effective length is 96 cm. Initially, a beam (H^+ and H^-) enters the beam extractor and encounters a dipole BM01 which separates H^+ and H^- by 40°. The subsequent six quadrupoles (QM1A to QM6A) are placed between dipoles so that the outgoing beam exactly matches the incoming beam shown in Fig. 7 for the H^+ beam. The effective length of each quadrupole is 40 cm and the maximum field gradient is less than 15 T/m. The settings of the quadrupoles in the H^- line are opposite to those in the H^+ line. The beam intensity depends upon the field from the superconducting coil. Fig. 8 shows the horizontal phase-space plots for the extracted H° beams ((b) and (d)) and the un-extracted H^- beams ((a) and (c)). The (a)

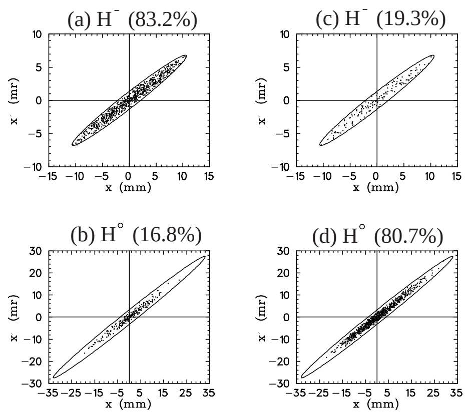

Figure 8: Horizontal phase-space plots for H^- and H° beams.

and (b) plots are the case which 16.8% of the H^- beam is extracted, and the (c) and (d) plots are for 80.7% of the H^- beam. The emittance of the initial beam is 14.4 π mm-mr. All the extracted beams with 0 to 100% can be enclosed with a large ellipse shown in (b) and (d) plots. The emittance of the large ellipse is 110 π mm-mr which is about a factor of eight larger than the initial beam. There is no emittance growth for the un-extracted H^- beam shown in (a) and (c) plots. The surviving H^- beam is bent by the stripper magnet where the bending angle is fixed at 20°. Fig. 9(a) shows the horizontal angle of H^- as a function of a longitudinal position. The stripper with high H^- extraction tends to bend H^- to a large angle initially. This effect provides the horizontal position difference for different stripper settings (Fig. 9(b)). This problem can be fixed by placing two 1° dipoles downstream of the stripper magnet, with a beam position monitor (BPM) between the dipoles for a diagnostic tool. For the 0% stripping case, the stripper bends H^- by 20° while bending less for the high intensity H^- stripping. Figs. 9(c) and (d) shows that the maximum angle difference is about 2° for two extreme beams at the center of the BPM. The maximum path difference is 3 mm. The remaining 2° or lesser angle is provided by two 1° dipoles and the alignment of the beam will be achieved by utilizing the BPM between two 1° dipoles and the second BPM placed upstream of BM03B. The H^- beam is then bent by BM03B and returns to the main linac by BM04 for further acceleration. The extracted H° beam drifts toward the foil located downstream of the stripper magnet and becomes H^+ . The quadrupole doublet (QM7 and QM8) transports the beam at the position labeled 'A' (Fig. 6) with the ± 1 cm beam size and ± 10.5 mr divergence. For proton therapy, the emittance growth is not disadvantageous because a lead plate is usually used to spread a pencil beam laterally.

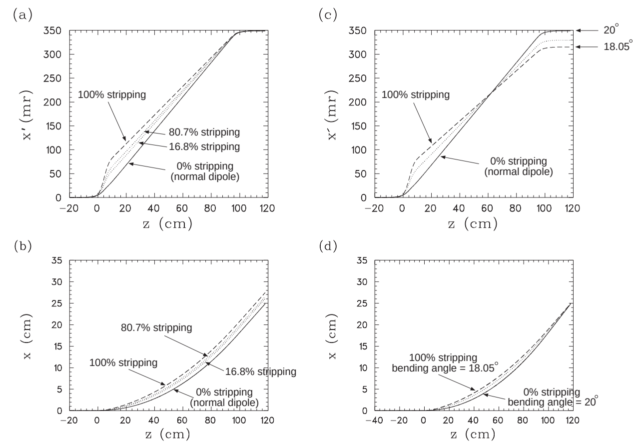

Figure 9: Tracking of un-extracted H^- beam.

5 SUMMARY

This paper discussed a feasibility of 260 MeV H^- beam extractor using a stripper magnet. It is shown that a desired intensity from 0 to 100% of H^- beam could be extracted and all the extracted beams from 0 to 100% could be enclosed with a large ellipse which represents a factor of eight emittance growth. The un-extracted H^- beam is returned to the main linac with no emittance growth.

6 ACKNOWLEDGMENT

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7 REFERENCES

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