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Comparison of Carbon Beam Profiles for Quadrupole and Octupole Lens

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1. Introduction

Just like light (a kind of electromagnetic wave) focused by using optical lenses, the carbon beam can be also focused or defocused by electric and magnetic lenses. Usually, a combination of two or three magnetic quadrupole lenses is used for focusing ions in accelerators [1]. On the transportation of carbon ions could be used focusing quadrupole lens or octupole lens with the respect of their purposes. It is usually employed for the focusing the beams with the quadrupole, which are consisted of an assembly of four magnets, where the magnets together produce a good approximation of quadrupole fields where ions are passing through. Octupole lens is applied to produce uniform beam profiles, rather then focusing the beam. In the study, the comparison of beam profiles from quadrupole and octupole lens is carried by the simulation method.

2. Simulation Methods

In this section the simulated magnetic field distributions and the method are described. Carbon ions with the velocity of 0.01c (c=3.8x108m/s) along the z-direction are sent through the system.

2.1 Quadrupole and Octupole Model and field distribution

For the focusing of carbon ions, magnetic lenses are very convenient, particularly where space is limited. Such lenses are simple to build and have less spherical aberration than that of axis symmetric electrostatic lenses. The magnetic field distributions from quadru pole and octupole lens are shown in Figs. 1 (a) and (b), where shows fourth-fold symmetric and eighth-fold symmetric distributions.

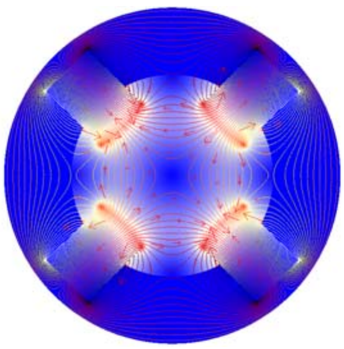

Fig. 1(a). The magnetic field density (M) inside of quadrupole lenses. The four magnets produce a good approximation of quadrupole fields along the central axis. The arrows indicate the direction of the field.

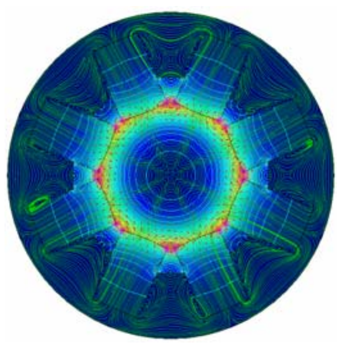

Fig. 1(b). The magnetic field density (M) inside of octupole lenses. The eight magnets produce a good approximation of octupole fields along the central axis.

2.2 Simulation methods

The magnetic field is described using the magneto-static equation, solving for the z-component of the magnetic potential A(Wb/m). The magnetic potential is everywhere defined from the equation, $B = \nabla \times A$. For the boundary condition, the magnetic field is approximately parallel to the exterior boundary of the iron cylinder. To enforce this, use the magnetic insulation boundary condition, stating that Az=0. Each carbon ion passing through the assembly (predefined magnetic fields) experiences Maxwell forces is equal to F=qv x B, where v (m/s) is the velocity of the ion. To find the transverse position as a function of time, we are solving numerically Newton's second law for each ion, qv x B = ma, where m is the ion mass (kg), and a its acceleration (m/s^2). The results of ray analysis of low energy carbon ions are presented in Figs. 2 and 3.

The focusing effect of the quadrupoles is demonstrated by tracking a number of ions starting evenly distributed along the circumstance of a circle with 1 mm diameter in the transverse plane, assumed to have a zero initial transverse velocity. Quadrupole focuses the ions along one of the transverse axes and defocuses it along the other one. For instance, the ions are defocused along the y-direction while focused along the x-direction at the first quadrupole. Unlikely, the octupole lens did not show any focusing effects, but the profile becomes wider evenly (see Fig. 3). From the Figs. 2 and 3, the final beam envelops are quite different from the case of quadrupole and octupole lens.

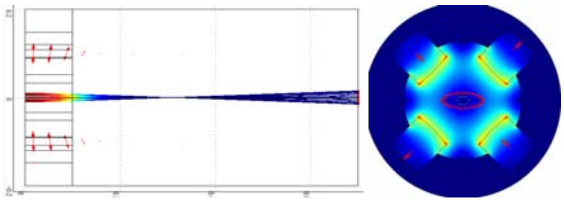

Fig. 2. Carbon ions trajectories for quadrupole magnets in y-z direction (left) and x-y plane (right). After passing the lens, the carbon ions are focused and defocused in y-direction, resulting smaller size with that of x-axis, where the ions are diverged from the initial point. The right figure shows the beam distribution, which is asymmetry shape.

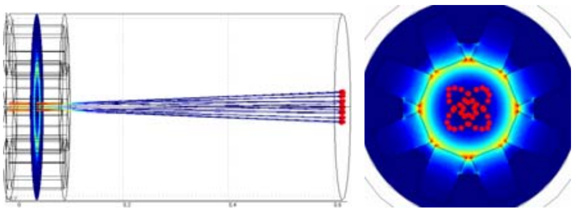

Fig. 3. The trajectories of carbon ions for octupole magnets in y-z direction (left) and x-y plane (right). After traveling from the lens, the carbon ions are distributed widely in four-fold symmetry at the plane of z=60 mm, where is shown in the right figure.

3. Results and Discussion

From the Figs. 4 and 5, the carbon ion distributions after traveling 50cm are indicated in x-y plane with different beam sizes. For the quadrupole lens, the shape of the distribution keeps similarly wider in both x and y directions. The traveling beam given with Gaussian distribution with the function of radius at the original point is also showed the same distribution at the destination plane z=60mm. However, the beam profile after octupole is quite different that from quadrupole magnet. It is resulted from the different magnetic field distribution inside the magnets. Also the Gaussian distributed carbon ions at the original point is showed a quite different distribution at the destination plane z=60mm.

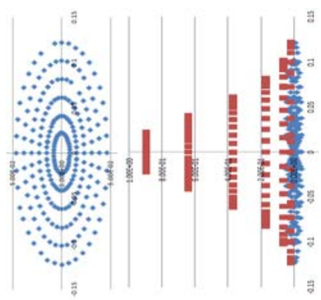

Fig. 4. The carbon ion distributions from quadrupole at the destination plane (z=60 mm) as a function of diameters of ions in x- and y-directions. The right figure indicated the Gaussian distribution, which is originally given the same distribution at the original plane.

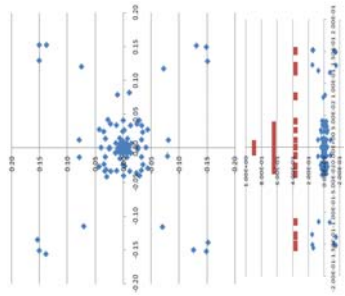

Fig. 5. The carbon ion distributions from octupole at the destination plane (z=60 mm) as a function of diameters of ions in x- and y-directions. The original Gaussian distribution of carbon ions are changed into a flatted distribution at the original plane.

In conclusion, the models we simulated are useful for focusing carbon ions and applying to make a micro-beam with an appropriate quadrupole magnet configuration. Octupole magnets could by used for uniform distribution of beam profile.

ACKNOWLEDGEMENTS

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[1] L.R. Burns, J.D. Bouas, S. Matteson, D.L. Weathers, Evaluation of a novel design for an electrostatic quadrupole triplet ion beam lens, Nucl. Ins. Meth. in Phys. Res. B261, 75-78 (2007).