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Tune-stabilized Linear-field, Nonscaling FFAG Lattice Design

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A hybrid design for a FFAG has been invented which uses a combination of edge and alternating-gradient focusing principles applied in a specific configuration to a combined-function magnet to stabilize tunes through an acceleration cycle which extends over a factor of 2-6 in momentum. Previous work on fixed-field alternating gradient (FFAG) accelerators have required the use of strong, high-order multipole fields to achieve this effect necessitating complex and larger-aperture magnetic components as in the radial or spiral sector FFAGs. Using normal conducting magnets, the final, extracted energy from this machine attains 400 MeV/nucleon and thus supports a carbon ion beam in the energy range of interest for cancer therapy. Competing machines for this application include a superconducting cyclotron and a synchrotron. The machine proposed here has the high current advantage of the cyclotron with the smaller radial aperture requirements that are more typical of the synchrotron; and as such represents a desirable innovation for therapy machines.

Summary

A hybrid design for a FFAG accelerator has been developed which successfully exploits strong-focusing to provide tune and envelope control, and then suppresses variations with beam energy using weak focusing. The net effect is to enlarge the momentum space which remains within the stable range in tune space. The conceptual approach is easy to understand, but difficult to simulate accurately with the limited capability of present optics codes, but work is in progress to present a more accurate representation.
With stabilized tunes, this FFAG behaves more like a synchrotron with multiple energies available for extraction and use, and with the attractive low-loss feature characteristic of synchrotrons. With its fixed fields, the magnets and power supplies are simple and this machine can be effectively operated continuously with high output beam current which is the noted strength of the cyclotron. The designs here specifically apply only normal conducting fields and still attain carbon therapy kinetic energies of 400 MeV/nucleon. Also like the synchrotron and unlike the cyclotron, there are multiple places to extract beam supporting multiple treatment rooms or other applications. This machine exhibits a reasonable dynamic aperture and performance due to the use of only linear gradient (quadrupole) and constant (dipole) fields which are known for their stable equations of motion.
Preliminary tracking studies at the injection energy using MAD indicate a reasonable, full, geometric dynamic aperture of 10-20 pi mm-mr. Although almost 3 orders of magnitude less than the comparable muon accelerator, which requires an exceptionally large acceptance for muons, this value is yet more than acceptable for the small emittances associated with proton and carbon beams.

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