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SELF-TRAPPING ELECTRON RING ACCELERATORS

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Summary

Simulations performed with a fluid MHD extension to the PIC plasma code CCUBE show that it is in principle possible to design liner-driven ring accelerators so that they generate their own trapping well. The liner elements are tapered in mass and respond in a predictable way to the driving acceleration. Currents arise as the liner moves through an imposed axial field, and if the liner shape is appropriate, a magnetic trapping well results. A cusp-injected electron ring is then introduced, trapped, and accelerated to high energies.

Introduction

An interesting way of increasing the energy stored in a rotating ring of charged particles is by increasing the magnetic field threading the ring axis. The ring must rotate more rapidly and compress in size as the field strength increases in order to remain in equilibrium with the field. One application of energetic particle rings is the compact toroid approach to controlled fusion energy. Other applications include microwave generation and particle beam generation. In general, however, making use of the increased energy stored in a compressed ring involves devising some procedure for extracting the ring. Generation of the ring and its injection into the accelerating configuration are also areas of concern. This paper describes a configuration for an electron ring accelerator that naturally produces, at appropriate times during the course of its evolution, a trapping well and an extraction potential. First, we describe the configuration and its schematic evolution. Then we describe the numerical simulations we have done and the code we have used, and finally, we point out directions for future work.

A Liner-Driven Ring Accelerator

We envision this accelerator as composed of an operating segment into which electrons are injected through a cusp field to form a ring, and from which the electrons are extracted through another cusp field to form a linear beam, followed by target and diagnostics as appropriate. The operating segment itself consists of one or more cylindrical liners parallel to an imposed magnetic field, which may operate either simultaneously to produce a "stacked" beam or sequentially to produce staging. Each of the liners will itself be divided into two parts longitudinally by a nonconducting ring. The liner is also tapered in density so that the least dense end is the extraction end. The liner is driven radially inward by use of explosives, for example.

As the cylindrical liner implodes, currents set up in the conducting segments will amplify the enclosed magnetic field. Field lines will leak out of the nonconducting ring portion of the liner, however, causing the interior field to be weaker beneath the nonconducting ring than in the other parts of the interior. This provides a natural trapping well for an electron ring that is now introduced into the system. As the liner continues to implode, the ring accelerates and compresses to remain in equilibrium with the field. Eventually the interior field becomes strong enough to decelerate the liner, but the portion of the liner that is decelerated first is the least dense end, i.e., the extraction end. A cone-shaped configuration now evolves, and a longitudinal gradient in the magnetic field developes. The accelerated ring then drifts out of the configuration, to be extracted through a cusp.

Simulations

In order to simulate the accelerator described in the previous section, we have used the primitive MHD package LINER within the particle-in-cell plasma code CCUBE. LINER treats a moving conducting fluid with a finite-element MHD scheme. For these simulations we used an incompressible equation of state. Electromagnetic fields in CCUBE produce currents within the moving liner, which has finite conductivity. These currents amplify the enclosed magnetic field. The fluid elements respond to the electromagnetic forces resulting from the amplified field. The nonconducting ring has been modeled as a gap in the liner, and the liner elements, four in number, are given different masses to produce the required density taper. Figure 1 shows the initial configuration.

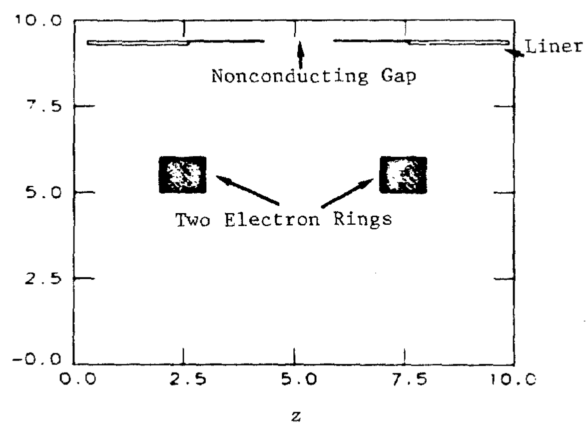

Fig. 1. Liner-driven ring accelerator initial configuration.

Two electron rings are initialized in equilibrium, in the fast rotational mode, with an axial magnetic field. The initial electron energy is approximately 5 MeV, the ring radius approximately 5 cm.

As the liner implodes, the rings coalesce and merge in the trapping well beneath the gap (Fig. 2). Eventually the dynamics of the tapered liner becomes important, and a cone-shaped liner is produced (Fig. 3). At this point the ring begins to drift out of the configuration. Its energy is now approximately 40 MeV, its radius approximately 1 cm.

The energy of beam extraction can be roughly "tuned" by varying the length and taper of the liner.

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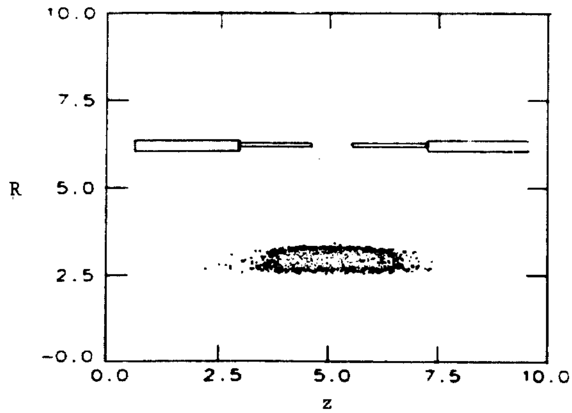

Fig. 2. Coalescence or rings.

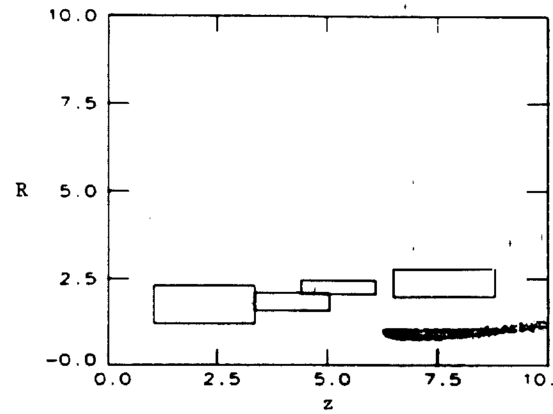

Fig. 3. Ring extraction.

Future Work

The liner package is being improved so as to be able to deal with more realistic equations of state, including electrical conductivity as a state variable, better resolution along the liner, and particle absorption and re-emission from the liner surfaces. These improvements will enable us to address questions of liner stability and integrity during the compression.

Acknowledgment

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