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Compact Torus Compression of Microwaves

Dennis W. Hewett
A. Bruce Langdon
X Division, Physics Department
Lawrence Livermore National Laboratory
Livermore, CA

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Dennis W. Hewett, A. Bruce Langdon
X Division, Physics Department
Lawrence Livermore National Laboratory
P. O. Box 808
Livermore, California 94550

The possibility that a compact torus (CT) might be accelerated to large velocities has been suggested by Hartman and Hammer(1). If this is feasible one application of these moving CTs might be to compress microwaves. The proposed mechanism, discussed in detail elsewhere(2), is that a coaxial vacuum region in front of a CT is prefilled with a number of normal electromagnetic modes on which the CT impinges.

A crucial assumption of this proposal is that the CT excludes the microwaves and therefore compresses them. Should the microwaves penentrate the CT, compression efficiency is diminished and significant C heating results. MFE applications in the same parameters regime have found electromagnetic radiation capable of penetrating, heating, and driving currents. We report here a cursory investigation of rf penetration using a 1-D version of a direct implicit PIC code.

Our study used a much simplified model which takes into account the relevant field orientations but allows gradients only in one spacial direction (axial). Figure 1 shows the CT-microwave geometry we have modeled. In our model, we look at a small region at the interface between the CT and a group of "target" TE modes.

The magnetic field of the low β CT can be considered to be homogeneous and static. The field of the TE mode is represented by a smaller rf component superposed on and in the same direction as the zeroth order CT field. Inhomogeneities in directions other than the axial direction are ignored. In the case reported here (Fig. 1), the bias field $B_0 = 1$ for all x, the density consists of piecewise linear segments with peak density n=1 between 25<x<35, and the incident rf amplitude is 0.3. For these choices $\omega_{pe}/\omega_{ce} = 1$ and $\omega_{lh} = 0.07\ \omega_{pe}$ at peak density.

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Even this simple inhomogeneous model is difficult to analysis. Assuming homogeneous density, standard analysis$^{(3)}$ gives the relation

$$\kappa^2 = \frac{\omega^2}{c^2} - \sum_j \frac{\omega^2\omega_{pj}}{c^2(\omega^2-\omega_{cj}^2)} - \frac{\left[\sum_j \frac{\omega_{pj}^2\omega_{cj}^2}{c(\omega^2-\omega_{cj}^2)}\right]^2}{1-\sum_j \frac{\omega_{pj}^2}{\omega^2-\omega_{cj}^2}} \qquad (1)$$

where the summations are over particle species j. We find k^2 positive, indicating propagation of the applied EM wave ω, in two regions. At extremely low n, we have a "vacuum-like" EM mode and for large enough densities the lower hybrid mode propagates. This implies a range of densities between these two extremes for which $k^2 < 0$ -- no mode can propagate. We find lower hybrid propagation can occur only if the density is large enough so that $\omega_{lh} < \omega$, or

$$\omega_{lh} = \sqrt{\frac{m_e}{m_i}\,\frac{n}{1+n/B_o^2}} > \omega. \qquad (2)$$

Inhomogeneous density profiles, as in Fig. 1, were evaluated using an implicit PIC model$^{(4)}$. A right-traveling external rf mode with frequency and amplitude is specified by boundary conditions. The frequency ω is chosen so that the mode would propagate in the homogeneous density region on the right side of Fig 1. We have chosen here $\omega = 0.05\ \omega_{pe}$ with $\omega_{lh} = 0.07\ \omega_{pe}$ so that a lower hybrid mode can propagate in the uniform density. The inhomogeneous density is almost entirely a "forbidden" region through which a small amplitude mode cannot propagate and would therefore be excluded and reflected to the left. For finite rf amplitudes nonlinear effects will become important and these effects coupled with the complexity of the inhomogeneity allow freedom which is properly dealt with only with simulation. Figure 2 shows a typical result of a large amplitude ($0.3\ B_o$) wave which nonlinearly penetrates the CT. The penetration is most evident in the ion v_x-x phase space which reveals that the shake back and forth in resonance with the incoming wave. In the early stages, some evidence of the rf reflection is indicated by the steeping of the density ramp near the critical density. However, at this amplitude the phenomena rapidly becomes nonlinear and is not observable in Fig. 2.

In summary one might expect, based on the homogeneous linear model, Eq. 1, that the rf energy might not penetrate if the external ω were larger than the ω_{lh} in the interior. Simulations verify this conjecture. For large amplitudes the leading edge of the CT is significantly eroded. The conclusion is that the CT may be able to compress TE modes if the initial CT peak density initially gives rise to an $\omega_{lh} < \omega$ -- the initial TE mode frequency. These may be strongly dependent on k.B = 0 -- a condition that is probably not satisfied in more realistic multidimensional geometries.

Recently we have considered suggestions that the magnetic field that precedes the moving CT (the field on which the rf is superposed on the left of our simulations) should be much smaller if not zero. Preliminary investigations verify that an inhomogeneous B which falls to a tenth of the interior value on the TE side indeed significantly reduces the rf penetration.

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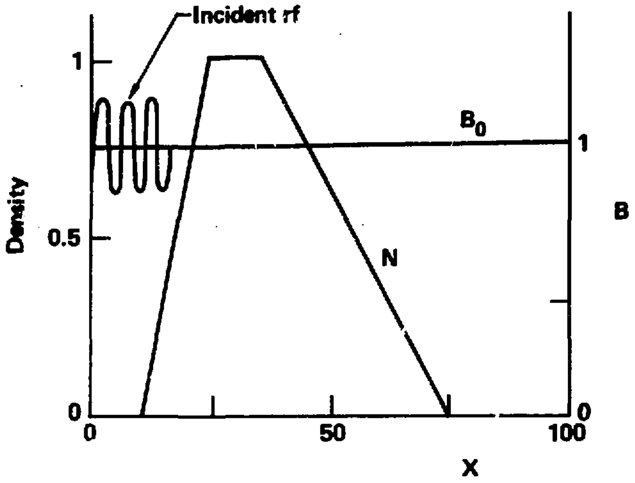

Fig. 1 Simplified model of CT, TE mode geometry.

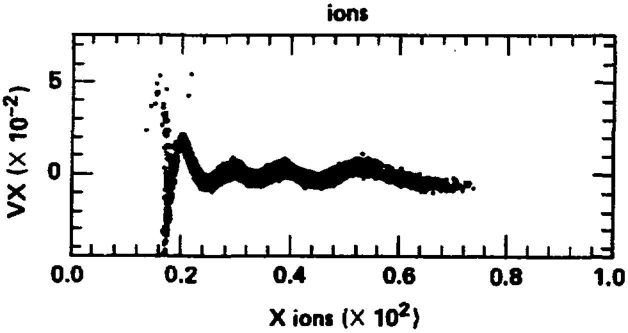

Fig. 2 Ion v_x-x phase space plot showing rf penetration for TE frequencies below the hybrid frequency at peak CT density.