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ICRF FARADAY SHIELD PLASMA SHEATH PHYSICS: THE PERKINS PARADIGM

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ABSTRACT

Using a 2-D nonlinear formulation which considers the plasma edge near a Faraday shield in a self consistent manner, progress is indicated in the modeling of the ion motion for a Perkins embodiment. Ambiguities in the formulation are also indicated, the resolution of which will provide significant insight into the impurities generation for ICRH antennas.

INTRODUCTION

Ion Cyclotron Heating (ICH) at high power densities (5-10 kW/cm^2) offers several challenges–one of which is the anticipated high rates of heavy metal impurity generation and outflux. An understanding of the plasma edge near such antennas is an important part of eliminating or mitigating this problem. The present work reports progress toward this understanding.

The plasma edge problem presents formidable difficulties of treatment, particularly near the ICH antenna. One difficulty is the extreme nonlinearity of the equations describing the plasma sheath for an edge plasma on the order of $10^{12}/\text{cm}^3$. A second is the dimensionality involved; the complex geometry near an ICH antenna, with a Faraday shield and local limiters, demands the imposition of boundary conditions in all three spatial dimensions. A third is the time scales involved; an accurate model may need to account for electron motion in the magnetized plasma over short electron time scales, ion motion over many rf/ion cyclotron periods, and impurity distribution evolution over long, quasi-steady state periods. The model also needs to connect with the properties of the bulk plasma, preferably in an iterative, self-consistent manner.

MATHEMATICAL FORMULATION

The Fokker-Planck equation for each species of charged particles, and Maxwell's equation for the potentials, in the Lorentz gauge, are considered:

$$\left\{\frac{\partial}{\partial t} + \mathbf{v}\bullet\nabla_r + \frac{q}{m}\left[\mathbf{v}\text{x}(\mathbf{B}_0 + \nabla\text{x}\mathbf{A}) - \nabla\phi - \frac{1}{c}\frac{\partial \mathbf{A}}{\partial t}\right]\bullet\nabla_v\right\} f(\mathbf{r},\mathbf{v},t) = \beta g(\mathbf{r},\mathbf{v}) \qquad (1)$$

$$\nabla^2\phi(\mathbf{r},t) = -4\pi\left\{N_{e0}\exp\left[e\left(\phi(\mathbf{r},t) - \phi_p(\mathbf{r},t)\right)/kT\right] - \int d\mathbf{v}\, f(\mathbf{r},\mathbf{v},t)\right\}, \qquad (2)$$

assuming a Boltzmann distribution for the electrons and neglecting $\partial^2\phi/\partial t^2$ (Debye length much smaller than free space wavelength). The determination of **A** in Eq. (1) in general can be taken from a solution of the

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homogeneous Helmholtz equation in 3-D [Ref. 1] or in at least 2-D [Ref. 2] or the 3-D scalar magnetostatic models, $\nabla^2\Psi = 0$ [Ref. 3], where Ψ is the magnetostatic potential.

The nonlinear formulation of Eqs. (1)-(2) constitutes a self-consistent description of: the sheath potentials, the onset of charge separation in the plasma, ponderomotive forces, ion Bernstein wave launching and damping, ion acoustic waves, edge plasma ion turbulence, sheath rectification, charged impurity ejection, and a whole host of near field phenomena, many of which are probably undiscovered at this point, but are expected to be important. This formulation is quite general and has been used numerically for long time scale sheath problems in the past [Ref. 4-5].

PERKINS' PARADIGM

An example that will be considered is the "Perkins" Faraday shield [Ref. 6] and associated paradigm. By use of Faraday's law one can replace the induction term, $\partial \mathbf{A}/\partial t$, in Eq. (1),by a boundary value problem on the scalar potential such as shown in Fig. 1. In the metallic elements $\mathbf{E}$ is assumed zero and thus (in Lorentz gauge) $\nabla\phi = (1/c)\, \partial \mathbf{A}/\partial t$. We will extend Perkins' analysis to two dimensions.

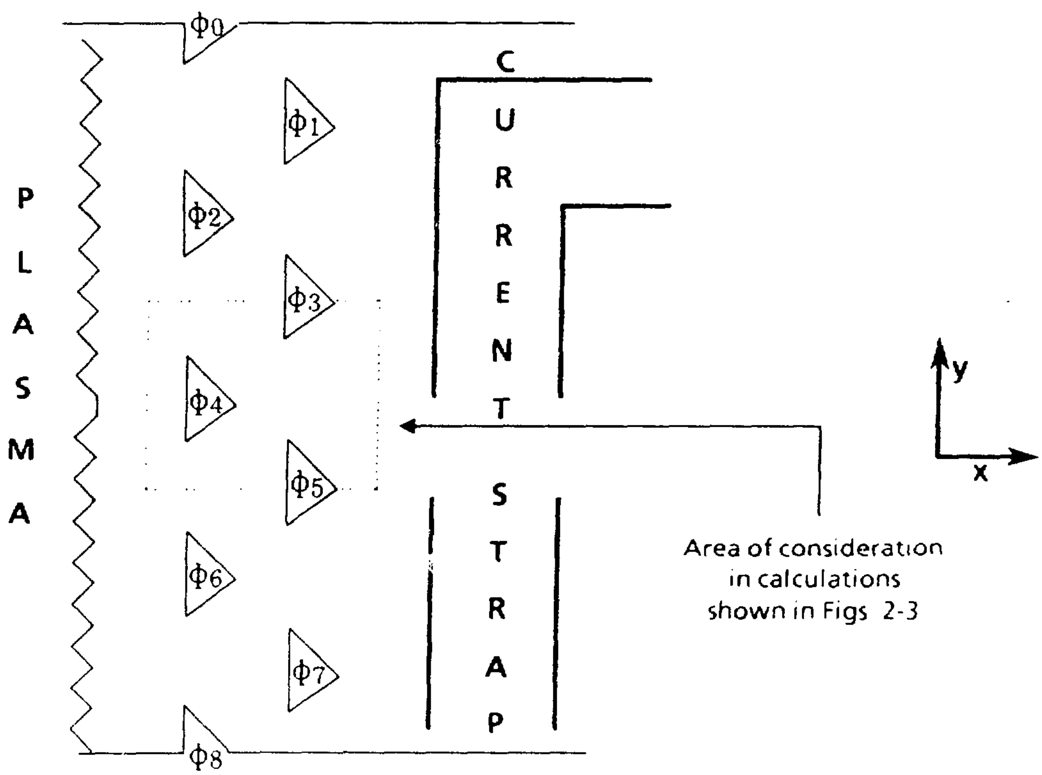

Fig. 1

As an illustrative calculation, we assume an immobile ion density in steady state for a case where the plasma potential, $\phi_p(\mathbf{r}, t)$, is uniform and equal to ϕ_5, which is the maximum potential considered (Fig. 2). The potential ϕ_4 is halfway between ϕ_3 and ϕ_5. It is the intention of this configuration that there would be sheath fields only on the right-hand side of the ϕ_4 electrode, so that sputtered material would go into the antenna or Faraday shield region as opposed to entering the confinement plasma. The presence of sheath fields on the left-hand side of the electrode is due to the imposition of the plasma potential $\phi_p(t)$, with respect to that electrode potential. Therefore, we can see the model and the results are very much dependent upon the local plasma potential. The local plasma potential is influenced by the potentials of the boundaries intersected by the magnetic field lines.

Time dependent ion trajectories from solution to Eqs. (1)-(2) are shown in Fig. 3. A uniform ion generation rate has been assumed. During this portion of rf cycle, ions are striking the ϕ_3 electrode with relatively high energy. The edge ions that missed the ϕ_5 electrode on the last half cycle are circulating due to the magnetic field and the negligible electric field. Near the ϕ_4 electrode, the dominant motion during this time interval is in the E X B direction.

CONCLUSIONS

The results in Fig. 3 are to be considered as preliminary in several respects: (1) There are ambiguities in the plasma potential which are an important feature of the model. This can be resolved by a full 3-D treatment of the boundary conditions; alternatively, plasma potentials may be imposed by geometrical consideration along a magnetic field line in conjunction with Faraday's law. (2) Numerical stability and variation of parameters' consistency have not yet been established. The status of ion acoustic-like waves routinely found in the solutions are not yet validated. Some space charge deposition issues have not yet been resolved.

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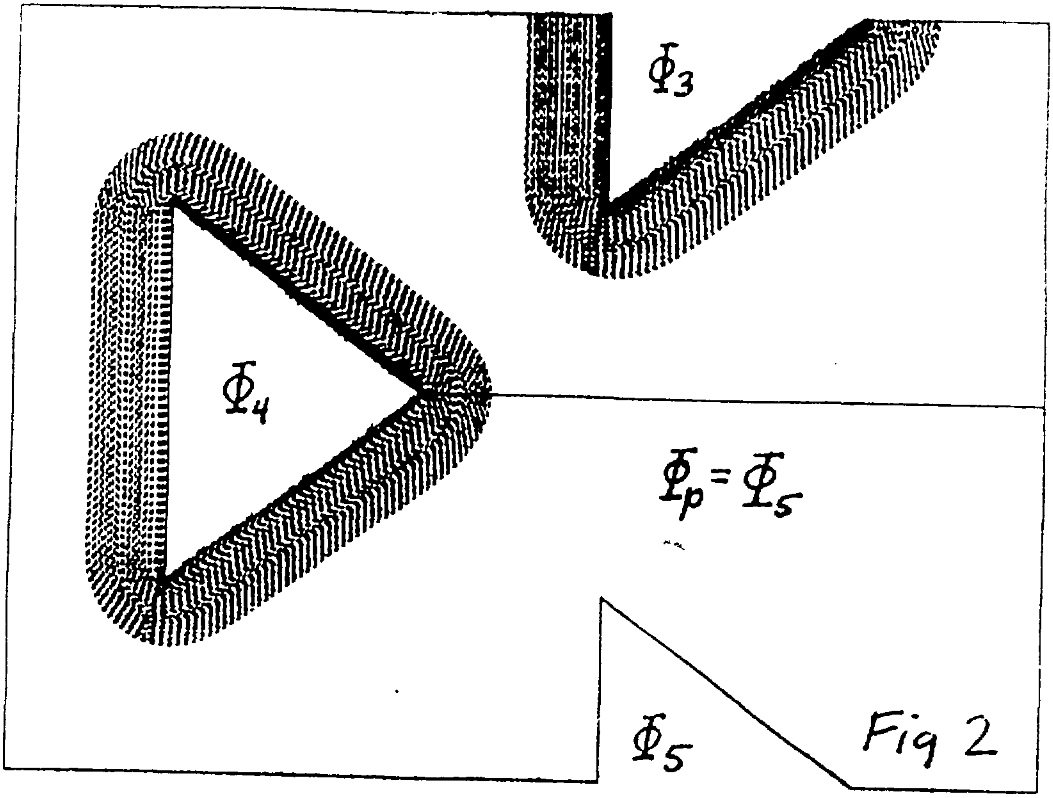

Fig 2

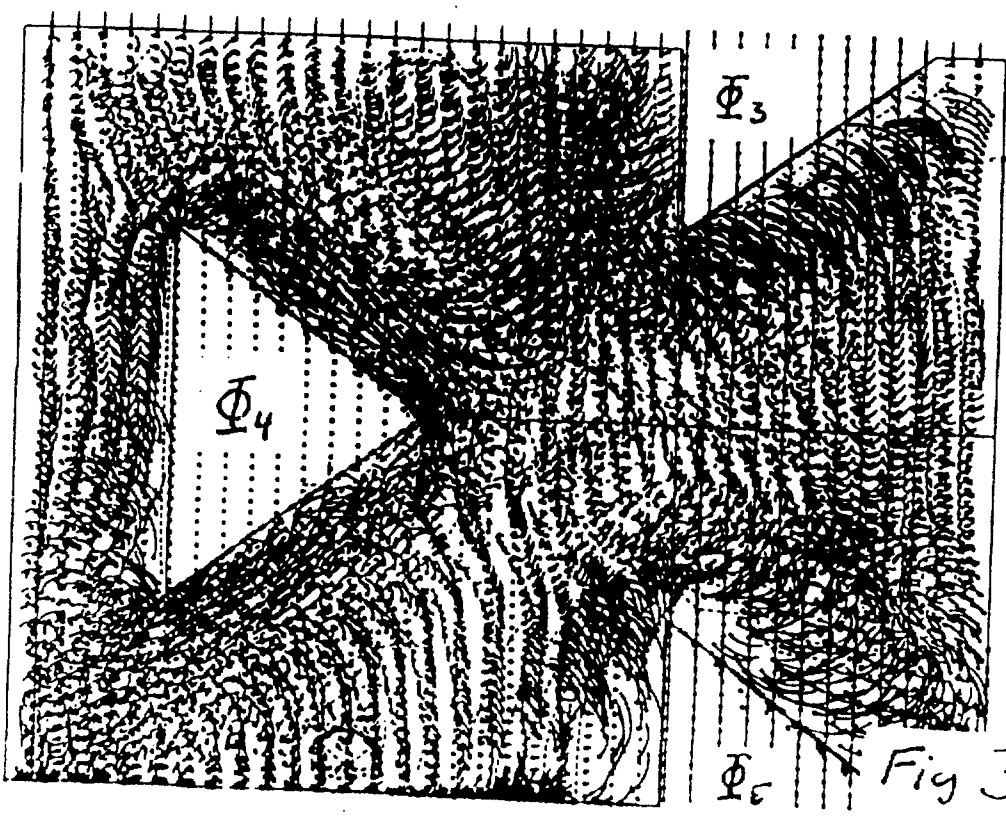

Fig 3