2D plasma wave propagation and absorption in electromagnetic plasma thrusters

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Besides being an interesting physical phenomenon by themselves, electromagnetic waves in plasmas provide an effective means for plasma generation and heating. Several advanced plasma thrusters, including the helicon plasma thruster (HPT) [1-4] and the electron cyclotron resonance thruster (ECRT) [5-6] employ different types of waves to this end. Therefore, understanding the propagation and interaction of the electromagnetic wave with the plasma is of utmost importance for the design of these devices.

At each frequency, wave phenomena depend strongly on plasma density and magnetic field strength, and can be markedly anisotropic. Different wave solutions exist depending on these parameters [7]. The plasma introduces non-linearities in the wave propagation, and a complex interaction exists between the wave and the velocity distribution function of each species—specially electrons—that can potentially lead to instabilities [8]. Several mechanisms participate in the power exchange between the wave and the plasma, which can be broadly decomposed into collisions-driven and collisionless. Resonances and cut-offs that occur as the wave enters a different parametric region are important features of wave propagation in this regard.

This work presents a two-dimensional wave-plasma interaction model for the study of electric propulsion applications. The model uses the linearized cold plasma dielectric tensor and a Yee numerical scheme [9] as the basis to study the parametric space. A kinetic submodel is used to treat correctly the regions near resonance fronts and provide the necessary corrections to the linearized model. The role of non-linear phenomena on wave propagation and the wave-averaged effects on plasma transport are discussed.

The model is then used to analyze power deposition mechanisms in different HPT- and ECRT-like configurations. The influence of the plasma profile, magnetic field geometry and strength, antenna shape, and position of reflective surfaces is assessed. Wave propagation into the plume region, which can be regarded as a loss term, is discussed. Finally, different domain boundary conditions are used to assess the role of the environment on the operation of the thruster.

References

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