FENNECS: a flexible code to simulate non-neutral plasmas trapped in Penning-like annular potential wells

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We present the electrostatic particle-in-cell code FENNECS capable of simulating non-neutral plasma clouds trapped in coaxial vacuum vessels with azimuthal symmetry but otherwise arbitrary electrode geometries. These clouds can be trapped either by magnetic mirrors or potential wells formed by the combination of externally applied electric fields and magnetic fields such as for example the ones characterizing Penning traps. In the case of pure electron plasmas, the self-consistent formation of the clouds by electron-neutral collisions and ionisation can be simulated. This code allows, for the first time, to simulate regimes in which strong azimuthal flows are imposed externally and lead to non-negligible electron-neutral ionizing collisions and radial drifts due to electron-neutral collisional drag. In this regime, this tool has been successfully applied [1, 2] in the domain of high power microwave sources used to heat magnetically confined fusion plasmas, namely gyrotrons, to study detrimental electron clouds that can form in the electron-gun region of the gyrotron and hinder the normal operation of the device [3, 4].

A detailed description of the physical model and numerical schemes used in the code is presented. In particular, we present a novel finite element method used for the first time in the domain of plasma physics and allowing the imposition of Dirichlet and Neumann boundary conditions on surfaces of arbitrary shape. In addition, the Monte Carlo methods used to simulate electron-neutral elastic and inelastic (ionisation) collisions as well as the effects of secondary electron emission due to impact ionisation on the electrodes are described. Verification test cases using manufactured solutions and validation of the simulations against experimental measurements in realistic gyrotron gun geometries are also presented. Finally, we present a series of applications of the code by considering the configuration of the future T-REX experiment [5] being built at the Swiss Plasma Center.

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