FENNECS: a flexible code to simulate high-density electron plasmas in Penning-like annular potential wells with large imposed flows and electron-neutral collisions

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We present the code FENNECS capable of simulating the self-consistent formation and evolution of electron clouds by electron-neutral collisions and ionisation in coaxial vacuum vessels where potential wells are present. These wells are formed by the combination of strong externally applied electric fields and magnetic fields and have some analogies with the ones present in Penning traps. However, contrary to typical Penning traps, the presence of large external radial electric fields ($E_r \approx 1-10$ MV/m) and axial magnetic fields ($B \approx 0.3$ T) imposes a fast azimuthal $\vec{E}\times\vec{B}$ drift which gives a high kinetic energy to the trapped electrons ($E_k \approx 0.1-1$ keV). This type of configuration is typical of some high power micro-wave sources ($f \approx 10-300$ GHz, $P \approx 1-2000$ kW), namely gyrotrons, used to heat magnetically confined fusion plasmas. In such configurations, the combination of electron trapping and high kinetic energies allows the ionisation of the neutral gas present in the vessel which causes the formation of clouds with densities close to the Brillouin limit and leads to radial and axial electronic currents. In the electron gun region of some gyrotrons [1], the presence of electron clouds has been linked to undesirable currents between the accelerating electrodes of the gun, which prevent their nominal operation [2]. This problem is very sensitive to small changes in the electrodes geometries or the magnetic field lines topology [3], and is currently solved by avoiding any potential wells in the design phase. This criterion is difficult to meet from an engineering point of view and motivates the need for a better understanding of this type of phenomena.

To study the electron cloud dynamics, as well as the evolution of the self-consistent trapping potential well, a 2D axisymmetric electrostatic particle-in-cell code called FENNECS has been developed. In this code, electron-neutral elastic and inelastic (ionisation) collisions are also simulated and new effects of secondary electron emission due to impact ionisation on the electrodes have been implemented and are presented. Other recent improvements allowing the definition of arbitrary electrodes geometries and using novel numerical methods are also described. Using this numerical model, we present verification test cases and validation simulations comparing experimental measurements and simulation results in realistic gyrotron gun geometries. Finally, we present a series of applications of the code by considering the configuration of the future T-REX experiment [4] being built at the Swiss Plasma Center.

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