§13. Two-dimensional Simulation Study on Charging of Dust Particle on Plasma-facing Wall —Model and Simulation Method—

Smirnov, R. (UCSD), Tomita, Y., Takizuka, T. (JAEA), Tskhakaya, D. (Univ. of Innsbruck)

The PIC simulation code two-dimensional in space (r,z) and three-dimensional in velocity space $\left(\upsilon_z, \upsilon_r, \upsilon_\theta\right)$ was originally developed for the simulations of a sheath with a dust particle. The plane wall at z = 0 is facing the plasma injected from the left boundary of the system $z = -L_s$, where is the bulk plasma containing equilibrium electrons and ions with the constant densities $n_{e0} = n_{i0} = n_0$ and the temperatures T_e, T_i. The system is cylindrically symmetric around the z-axis and limited in the r direction by the outer radial boundary $r = L_r$. A spherical conductive dust particle with a radius R_d attached to the wall is represented as a half-circle in the (z, r) space. There is no magnetic field in the system. The wall and the dust particle surfaces are assumed perfectly absorbing for the incident plasma particles, so that no secondary emission is considered. The electrons are injected with the half-Maxwellian velocity distribution function in the z direction with the fixed temperature T_e and the full-Maxwellian distribution in the r direction with the same temperature T_e. Ions have the temperature T_i in the both directions for the full-Maxwellian velocity distribution along the r direction and the shifted Maxwellian distribution with the shift velocity u_0 along the z direction. The ion shift velocity is determined in order to avoid any unphysical potential changes at the left boundary. The left boundary of the system is transparent for outgoing particles, which are excluded from the simulation when they cross the boundary. On the outer radial boundary we applied the "inverse-reflection" boundary conditions for the plasma particles, where all particles going out of the simulated system through the outer radial boundary are re-injected back into the system with reversed trajectories using time reversibility of motion equations in a constant force field. If we assume that our system is in a steady state and a local velocity distribution function of plasma particles is symmetric (in respect to the zero velocity) near the outer radial boundary, then an "inversely symmetric" particle with the opposite velocity will always exist. We assume that the motion along the z direction of the particle going out of the system through the outer radial boundary is the same as the motion of the "inversely reflected" incoming particle. This assumption is correct when the radial variation of any force acting along the z direction is not large on the $\upsilon_r \Delta t$ scale that is easy to achieve for the sufficiently remote outer radial boundary from the dust particle and a strong electric field along the z -axis in the sheath. These boundary conditions are also valid for the case when a radial force is acting on particles at the outer radial boundary. In order to avoid a singularity of motion equations at r = 0, we use a local Cartesian coordinates for solution of the motion equations. After updating of the particles coordinates and velocities, we transform them back to the cylindrical coordinates for charge weighting on the mesh procedure.

To find the field distribution we solve the Poisson's equation in the following form

$$\nabla\kappa\left(z,r\right)\nabla\varphi\left(z,r\right) = -\rho^{free}\left(z,r\right)/\varepsilon_0 \,, \qquad (1)$$

where ρ^{free} (z, r) is the local density of free charges, φ(z, r) is the local electric potential, and κ(z, r) is the local dielectric constant, which has value $\kappa = \kappa_d$ inside the dust particle and κ = 1 outside it. For the boundary conditions we assume that the wall has the fixed potential φ_w and the potential of the left axial boundary of the system is zero. At the axis r = 0 the radial component of the electric field should be zero due to the cylindrical symmetry of the system and at the outer radial boundary $r = L_r$ we also assume the zero radial electric field. We used a matrix method for solving of the Poisson's equation (1), because the (z, r) variables in this equation are inseparable due to the spherical shape of the dust particle and the corresponding half-circle shape of the local dielectric constant distribution κ(z, r). In the case of conductive dust particle, the dust dielectric constant $\kappa_d \to \infty$, which we simulate by a sufficiently large value $\kappa_d = 10^6$. To treat the absorbed charges we introduce a uniform grid with the angle on the dust surface with K cells. Each cell accumulates the free absorbed charges in it that form the free charge of the cell, which is assigned to its center. The free charge of the cell, then, is weighted on the spatial mesh of the system to solve the Poisson's equation (1).

To clarify the limits of the one-dimensional theoretical model of dust release from the plasma-facing wall we simulated charge of the dust particle on the wall with the wall potential and the dust particle radius as variable parameters. In Fig.1, the dependencies of the charge of the dust particle placed on the plasma-facing wall with potential $e\varphi_w/T_e$ = -5.0 on the particle radius are shown according to the self-consistent simulations (circles) and the one-dimensional theoretical formula (solid line [1]).

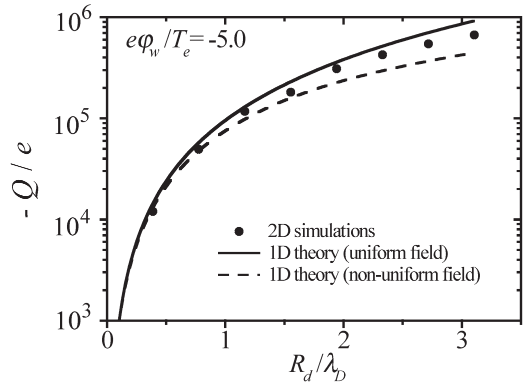

Fig. 1 Dependence of the charge of the spherical conducting dust particle placed on the wall on the particle radius for the wall potential value $e\varphi_w/T_e$ = -5.0.

Reference

1) Tomita, Y., Smirnov, R., Takizuka, T., and Tskhakaya D., Contrib. to Plasma Physics, **46** (2006) 617.