§12. Simulation Study on Transport of Charged Dust Particles in Plasmas

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In plasmas, dust particles are negatively charged up to form so-called ``plasma crystals'' under the strong Coulomb interaction among the dust particles. There have been many experiments on the dust particles and various interesting features of dust-particle plasma have been clarified. Moreover, the dust particles have attracted a strong interest due to their important roles as contamination source in the material processing and fusion plasmas. It is an essential issue to understand and control the collective motion of dust particles levitating in plasmas in order to remove dust particles from the processing and fusion plasmas. Particularly, the control of an electrostatic field is quite important, because the large charged particles are very sensitive to the electric field in plasma, and new dust-particle structures such as vortices and void are generated and controlled by an appropriate potential structure.

In order to investigate the effect of ion drag force on dust transport, we carry out a two-dimensional numerical calculation on the dust-particle orbit by solving the equation of motion of dust particles, including the effects of the potential structure and the ion drag force. The equation of motion of dust particle is given by the following equation,

$$m_d \frac{d\vec{v_d}}{dt} = \sum_{j=1, i\neq j}^{N} \frac{Q_{p,i} Q_{p,j}}{4\pi\varepsilon_o |\vec{r_{ij}}|^2} \exp\left(-\frac{|\vec{r_{ij}}|}{\lambda_{De}}\right) \frac{\vec{r_{ij}}}{|\vec{r_{ij}}|} - Q_{p,i} \nabla \phi_e + \vec{F_i} + \vec{F_{Nd}}.$$

First term in the right-hand side shows the electrostatic interaction among dust particles. The inter-particle potential is assumed to be the Yukawa type. Second term represents the electrostatic force acting on the dust particle due to the external potential ϕ_e. We assume a parabolic confining potential in radial direction. Third term shows the ion drag force F_i due to the Coulomb collision between ion and dust particle. Some models on F_i has been reported and discussed and we adopt the simple model by M. S. Barrnes [1]. F_i is given by the sum of the force F_{ic} due to the collection of positive ion and the force F_{io} due to the Coulomb interaction (no collection of positive ion). F_{ic} and F_{io} are expressed by the following equations, respectively,

$$\vec{F_{ic}} = n_i v_{is} m_i \vec{v_i} \pi r_c^2,$$

$$\vec{F_{io}} = n_i v_{is} m_i \vec{v_i} \pi r_{\pi/2}^2 \Gamma_p,$$

where $v_{th,i}$ is the ion thermal velocity, v_i is the ion drift velocity, v_{is} is $(v_{th,i}^2 + v_i^2)^{1/2}$, r_c is the collection impact parameter, $r_{\pi/2}$ is the impact parameter with orbit angle of $\pi/2$, and Γ_p is the Coulomb logarithm.

We calculated on dust-particle motions near the metal plate. In the absence of the ion drag force, the dust particles stop at their equilibrium positions in a potential well due to energy dissipation from the friction force. When the ion drag force F_i becomes finite, the particles are driven to have finite velocity in the steady state. Figure 1 shows the orbit of dust-particle motion for ion density $n_i = 7 \times 10^9$ cm^{-3} and dust-particle number $N_d = 2000$, respectively. Approaching to the metal plate, dust particles are gradually accelerated toward the metal plate edge region from the side surface region to form clockwise and anticlockwise rotations on right and left sides of the metal plate, respectively. This clearly demonstrates that the ion drag force plays an important role on dust-particle behavior in plasma, and detailed analysis of the ion drag force would be quite useful for controlling the dust particles in the processing and fusion plasma.

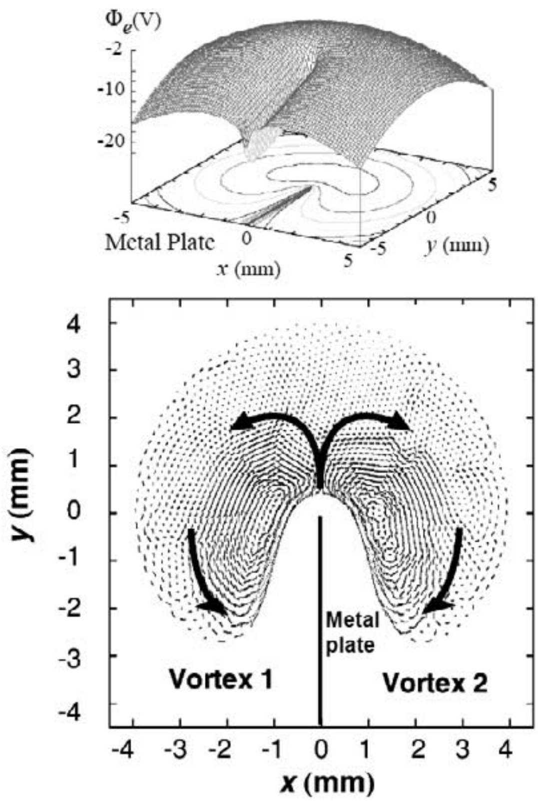

Fig. 1: The orbit of dust-particle motion at dust-particle number $N_d = 2000$ and ion density $n_i = 7 \times 10^9$ cm^{-3}.

1) Barnes, S. et al.: Physical Review Letters **68** (1992) 313.