MAGNETIZED DUSTY SHEATHS

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INTRODUCTION

Magnetized sheaths exist at the material walls of fusion devices (divertors, limiters, etc) and determine particle and energy fluxes to the walls influencing the overall operation of the fusion devices [1]. Investigations of the sheaths are started long ago [2] and are prolonged intensively now [3-5]. It was established recently that dust particles can be created in fusion devices due to the plasma-wall interaction [6]. Detail investigations of the helical divertor operation and erosion/deposition at target surfaces in LHD (Large Helical Device, NIFS, Japan) shown that dust particles with size of 3-15 μm were sampling in various regions of LHD [7]. It can be expected a remarkable influence of the dust particles on the magnetized sheaths of LHD due to a continuous selective collection of background electrons and ions by the dust particles. The collection can cause an essential change of both electron and ion energy distribution functions as well as an ion flux in sheaths so that spatial distributions of plasma parameters in magnetized sheaths can be essentially changed [5]. The aim of the work is the computer simulation of magnetized dusty sheaths for conditions close to the LHD edge plasma.

MODEL

Sheaths are investigated very often without a consideration of presheaths due to essential differed space and time scales of both regions. Of course, boundary conditions at a sheath edge have to be formulated at the investigations. However the Bohm's boundary conditions used in various works very often for sheaths in collisionless plasmas are not self-consistent due to an acceleration of ions in presheaths to the ion sound speed from undisturbed plasma. Therefore in this work, it is developed the relaxation model for magnetized sheaths without special boundary conditions for the sheaths. The model was used earlier for investigations of non-magnetized dusty sheaths [8-10]. The model is based on a study of a temporal evolution of one-dimensional slab plasma, which include a sheath and a part of presheath.

It is assumed that the collisionless quasi-neutral plasma is uniform initially and bounded at the left by an electrode (wall). The plasma consists of electrons with density n_{eo} and temperatures T_{eo} as well as hydrogen ions with a density n_{io} and a temperature T_{io} as well as motionless spherical neutral dust particles of given radius R_d. The dust particles are distributed close to the electrode (wall) according to a given distribution. The magnetic field B with a given profile along the normal with the electrode is applied to the plasma under the angle θ with the normal. The plasma evolution starts after a start of a collection of background electrons and ions by the electrode (wall) and dust particles, which are charged due to the collection. Scattering of electrons and ions by dust particles takes place due to a large size of dust particles.

The PIC/MCC method (1D3V model) described earlier [11] in detail for plasmas without dust particles was developed then [8-10] for computer simulations of the dusty plasma evolution. The method is developed in this work for simulations of magnetized sheaths. The simulation region size is chosen equal to 100-500 the Debye length so that the region exceeds essentially a sheath size. The electrode (wall) is chosen as the left boundary of the simulation region whereas the right boundary is located in a presheath where the plasma is quasi-neutral during the plasma evolution. The continuous exchange by superparticles takes place on the right boundary of the simulation region that has to be taken into account at the computer simulation. In this work, the original model of the exchange was developed which takes into account the self-consistent change of the electric potential as well as electron and ion energy distribution functions on the right boundary. The electrode (wall) collects a "superparticle" if its center reaches the electrode (wall) surface.

The Monte Carlo technique [11] is used to describe interactions of electrons and ions with dust particles. The interactions include Coulomb's scattering of electrons and ions with dust particles, as well as the electron and ion collection by dust particles. In addition to a usual PIC/MCC scheme, the weighting procedure is used also for the determination of a superparticle charge part, which is interacting with neighbour dust particles. The cross-sections of electron and ion collection by immobile dust particles are taken according to the Orbit Motion Limited (OML) theory [12]. The Coulomb cross-section for electron and ion scattering by immobile dust particles is taken from [13].

Simulations start with an initially uniform distribution of electrons and ions and are prolonged usually up to a moment when the rarefaction wave reached the right boundary of the simulation region. At this moment, the relative change of the self-consistent electric potential in the sheath was not exceeding about 5 % during 5 ion plasma periods.

A possibility to simulate the evolution of the temporal evolution of one-dimensional slab plasma without dust particles and/or the magnetic field is foreseen for a comparison with the investigated case of magnetized sheaths.

RESULTS

Simulations of 1D magnetized dusty sheaths are carried out for plasma parameters close to ones measured in LHD (NIFS, Japan) divertor [14] and shown in Table 1. As can be seen in the table, the plasma with the electron density $n_e \sim 10^{12}\ cm^{-3}$ and about equal electron $T_e \sim 25\ eV$ and ion $T_i \sim 30\ eV$ temperatures consist of dust particles with radius $R_d \sim 2.5–15\ \mu m$. The magnetic field $B_o \sim 1\ T$ is directed on the divertor plate under angles $\theta \sim 40 - 64^o$ with the normal to the plate surface. Chosen simulation parameters are enclosed in brackets in the Table 1.

Table 1

n_e, cm^{-3}	T_e, eV	T_i, eV	B, T	θ, degree	R_d, μm
$\sim 10^{12}$ (10^{12})	~ 25 (25)	~ 30 (25)	1	40–64 (45)	2.5–15 (~ 3)

Corresponding values of the electron Debye length L_{De}, the electron r_L and ion R_L, gyroradius, and its ratios are shown in Table 2. As can be seen in Table 2, the ion gyroradius R_L, exceeds essentially the electron Debye length L_{De}

Table 2

L_{De}, cm	r_L, cm (for e)	R_L, cm (for H^+)	r_L/L_{De}	R_L/L_{De}
$3.7 \cdot 10^{-3}$	$1.7 \cdot 10^{-3}$	0.08	0.46	21.6

Unfortunately, the density of dust particles is not known in the LHD divertor plasma (as well as in other fusion devices) although a surface mass density of dust collected from LHD was measured and consists of $0.1 - 0.2\ g/m^2$ [14]. The surface density does not allow estimating the density of dust particle in LHD, because the collection of dust particles is not continues due to charge of both dust particles and collection surfaces. In order to study an influence of dust particles on magnetized sheaths, the density of dust particles is chosen equal to $10^4\ cm^{-3}$ close to the divertor plate. The density corresponds to the number of dust particles in a Debay cube $N_d = 1$, at which an influence of dust particles on non-magnetized sheaths is essential [15].

Typical results of computer simulations are shown in Fig.1–3 where the spatial coordinate x is divided by the initial Debye length $\lambda_d = (kT_e/4\pi n_o e^2)^{1/2}$ and the time t is multiplied by the initial ion plasma frequency $\omega_{i0} = (4\pi n_o e^2/M)^{1/2}$. The figures consist of spatial-temporal distributions of plasma parameters, which evolve due to a collection of electrons and ions by the electrode (wall) and dust particles. Some figures consists of spatial distributions of the dust particle number N_d in a Debye cube in order to mark out the dusty region and to make clearer understanding spatial distributions of other parameters. The results are shown at a condition that the number N_d of dust particles in a Debye cube is constant at $x < x_o = 16$ and equal to $N_{do} = 1$. The number N_d decreases according to $N_d = N_{do} \exp(-(x- x_o)^2/w^2)$ at $x_o < x < x_1$ where $w = 6\lambda_d$. Dust particles absent at $x > x_1 = 28$. The profile of the magnetic field B is given by $B = B_o \exp(-x^2/a^2)$ where $a = 100\lambda_d$.

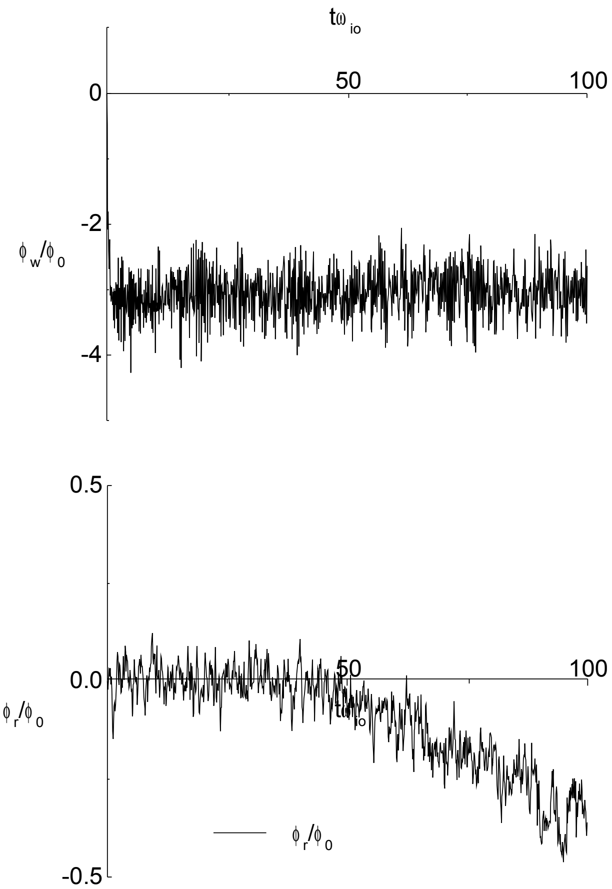

Fig.1. The evolution of boundary potentials.

Obtained results show that disturbance of ion and electron densities is formed close to the electrode (wall)

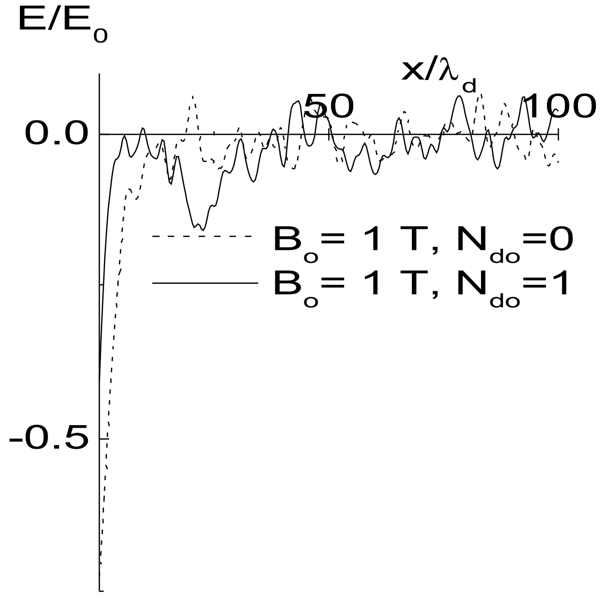

Fig.2. Spatial distributions of the electric field E divided by the characteristic potential $E_o = kT_e/\lambda_D$.

initially due to the ion collection. The disturbance transits continuously in the undisturbed plasma so that the disturbance wave propagates in the dusty region initially and than penetrates into plasma without dust particles converting into a rarefaction wave. The evolution of boundary potentials divided by the characteristic potential $\phi_o = kT_e/e$ accompanied the wave transit is shown in Fig. 1. As can be seen in Fig. 1, the electrode (wall) potential ϕ_w changes initially very quickly and the potential is oscillating then. The potential ϕ_r on the right boundary is oscillating also but it remarkable changes only after an arrival of the rarefaction wave to the boundary. Simulations show that a ratio of oscillation amplitude to a mean boundary potential is growing with an increase of the magnetic field and its angle with the normal to the electrode (wall) surface.

Spatial distributions of the electric field E divided by the characteristic electric field $E_o = kT_e/\lambda_D$ is shown in Fig. 2 after an establishment of boundary potentials by solid and dashed line for magnetized sheaths in cases with and without dust particles, respectively. As can be seen in Fig.2, dust particles decrease the electric field in the sheath and create an additional electric field close to a boundary of dust particles like to a sheath in an oblique magnetic field investigated earlier [16]. As simulations show, the increase of the magnetic field or its angle with the normal to the electrode surface causes the decrease of the electric field in the magnetized sheaths.

The established dust particle charge $n_d\, q_d$ divided by the initial ion charge $n_o\, e$ is shown in Fig. 3 for conditions of Fig. 2. As can be seen in Fig. 3, there is not an essential difference between both cases.

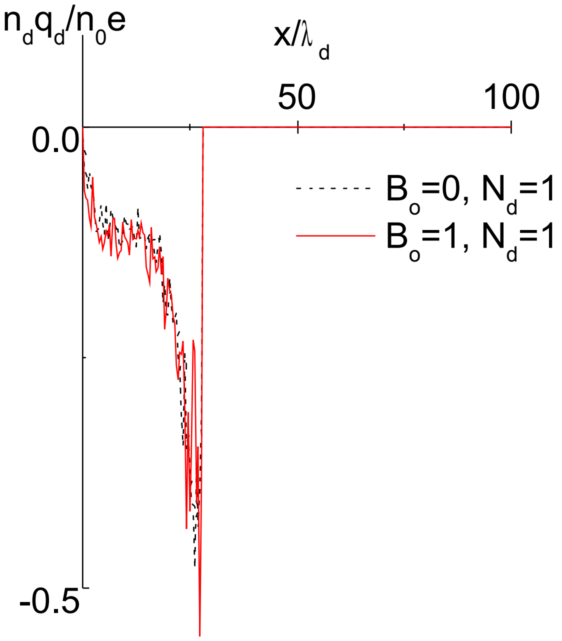

Fig.3.The established dust particle charge $n_d\, q_d$ divided by the initial ion charge $n_o\, e$.

CONCLUSION

The PIC/MC computer simulation of magnetized dusty sheaths is carried out by using an evolution of one-dimensional slab plasma for conditions close to the LHD divertor plasma consisting of dust particles with size of 3-15 mm. Obtained results show the existence of oscillations of a self-consistent potential in magnetized dusty sheaths including boundary potentials. The role of the oscillations is growing at the increase of the magnetic field and its angle with the normal to the electrode surface. Dust particles weaken magnetized sheaths and create additional sheaths close to a boundary of dust particles. The magnetic field does not influence on the dust particle charge.

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