PARTICLE TRANSPORT: MODEL OF NON-STATIONARY FLUCTUATIONS

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Particle dynamics in non-uniform magnetic field for a slab and a cylinder is presented. The presence of electric field with low frequency drift (LFD) and lower hybrid drift (LHD) waves is considered. Drift waves as the possible cause of an anomalous transport in plasma are used in calculations. Non-stationary fluctuations of the electrostatic field of the plasma waves are modeled. The stochastization of the particles is studied numerically.
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INTRODUCTION

Anomalous transport is a result of complex processes of interactions of the particles with electrostatic and/or electromagnetic field produced by waves propagating in plasma.

Investigation of anomalous transport includes two problems: examination of wave fields and action by one on particles. Rigorous mathematical set of equations for reconstruction of the closed to real picture of the field in plasma is lacking. Consequently different models of wave fields on a base both experimental data and theoretical considerations are formulated.

The most known model is so-called quasi-linear theory [1,2]. In this theory one model of the wave field with some assumptions has been formulated [3]. Under these assumptions the Vlasov-Maxwell equations may be reduced to MHD set of equations including the convective anomalous transport terms (mass and energy) as well as dispersion relations [4,5]. In this theory anomalous transport properties as a function of the imaginary part of ion or electron contribution to dispersion relation are expressed.

Recently W. Horton and his team [6,7] have proposed a new model of wave field in plasma. First of all arising of electrostatic fluctuations as a result of the summing up of wave modes is taken into account. Therefore any charged particle perceives separated fluctuations as strong single perturbation against a background of a weak noise. This interaction is the main reason of anomalous transport within the context of this model. This very important feature demands especial careful investigation. The mentioned papers contain only initial ideas. The main purpose of one is to calculate the motion of the separate particles in the collisionless plasma of tokamak. The similar works for field reversed configuration (FRC) and tandem mirror made in [8,9]. But investigations of anomalous transport for toroidal systems are confronted by the big difficulties (compare with open end systems). This problem has been demonstrated clearly at the recent paper [10]. In contrast of tokamak FRC system allows to solve the problem of anomalous transport completely.

Wave - soliton-like wave interaction and other phenomena must be included in the model of anomalous transport. But existing theories of the nonlinear wave processes in plasma are too complicated and they cannot be the base for calculations of anomalous processes in plasma.

The main purpose of our work is developing an approach taking into account the field fluctuations for the high plasma beta.

This problem is divided into following three parts.

a) Derivation of the dispersion relation in the range close to lower hybrid drift frequencies.

b) Analysis of fluctuations produced by simultaneously propagating wave modes.

c) Working out of the approach taking into account non-uniformity both plasma parameters and magnetic field.

Calculations were carried out for the model of the stochastic processes of particle-particle interaction and electrostatic fluctuations. These fluctuations are packets of waves propagating along azimuthal direction of the non-uniform cylindrical plasma. The above mentioned approximations allow to obtain stochastic motion and orbits of charged particles. The calculations have shown that the short-wave fluctuations render the weak influence on the energetic particle (the velocity vastly exceeds the thermal velocity).

A NEW APPROACH

A new approach to examine the transport properties of the plasma observed in the experiments is developed. Field fluctuations and particles transfer in plasma with strong inhomogeneity of density and magnetic field is presented. Proposed theoretical analysis takes into account the real spatial structure of plasma and non-uniform magnetic field. Influence of magnetic field and plasma density profiles on diffusion is studied. Non-stationary electromagnetic field of the waves propagated in plasma is modeled.

This paper aims to study a new model of transport plasma. The most important distinction of this model from the transport model [5] is taking into account the real structure of plasma geometry and magnetic field. Influence of complex radial dependence of magnetic field $B(r)$ and density $n(r)$ on confinement time may be investigated by this approximation and resolved for various plasma areas where different types of instabilities are arising.

Space localization of electrostatic oscillations is considered and wave spectrum influence on the transport properties is studied at first time. Feature of the proposed system is the supposition of the wave-harmonics with the formation of two regions on the time scale: soliton-like impulses with peak shape and noises dividing impulses. It is important that transport processes may be appeared by action of impulses only. It is shown that the intensity of the electric field in noise region is significant less than maximum values of field in impulse (see Figure). Form of the impulse, its duration, and interval between impulses are defined by number of harmonics in packet, its amplitude, frequency, and wave length.

Presence of dispersion in plasma is also takes into consideration. Dispersion of the electrostatic waves has essential influence on the plasma particle transport because leads to decay of impulses cause of the different phase velocites of independent harmonics. Therefore, taking into account dispersion leads to non-stationary of electrostatic field and besides the non-stationary is determined not only by motion of soliton with group phase velocity of packet, but its decay and formation of a new soliton.
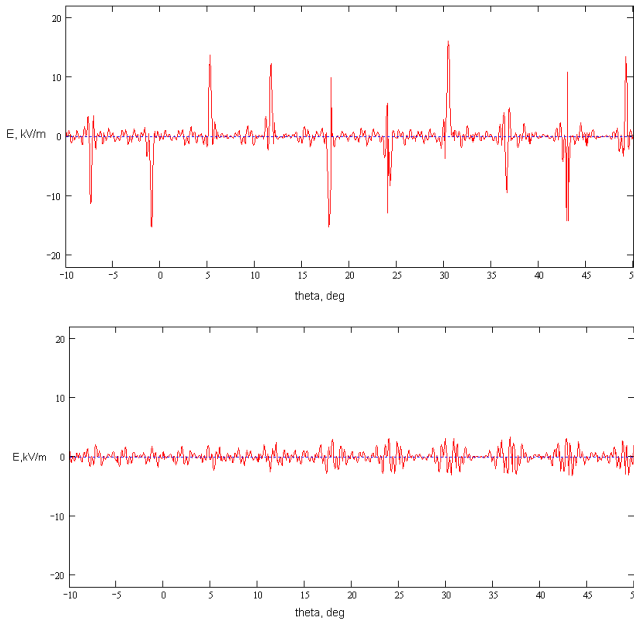
Electric field fluctuations (LHD oscillations) vs azimuthal angle. For both figures the number of layers in the plasma volume is equal 10, 20 harmonics in each one

Electric field intensity is shown in the Figure. Harmonics have Gaussian transversal profile, its dispersion is equal to layers width so that fringes of profile intersect two adjacent layers. Amplitude/energy of oscillations is about 2,5% of thermal energy.

MODEL OF THE WAVE FIELD

The main features of the wave field are the following.
1) The occurrence of the weak background oscillations in plasma: their averaged values a such that they exert negligible action on particles.

2) On the background of weak wave oscillations the wave packets are formed.
3) The different parameters of the wave modes (e.g. phase velocity) depend on coordinate directed along transport flows.
4) The reason of anomalous transport is the influence of the big field fluctuations on the particles.
5) As the main types of oscillations that are responsible for anomalous transport the lower hybrid and low frequency drift oscillations are considered.

Therefore in general the wave field is complex three-dimensional non-stationary formation.

Analysis of the particles motion is reused to calculations of interactions particles with the big fluctuations.

Such model provides stochastic behavior of the particles motion automatically.

The important question of magnetic configuration is resonance conditions for plasma oscillations. The formation of the wave field depends on these conditions. In toroidal systems discrete conditions occur [11]. For cylindrical plasma with straight magnetic force lines the resonance conditions are continuous if azimuthal propagation of waves is considered. Therefore wave modes can be excited in any radius where corresponding type of wave is instable.

So-called local and global models of wave fields for toroidal systems in sense of above mentioned works of W. Horton et al. are not adequate for cylindrical systems because of indicated differences of resonance conditions. In cylindrical plasma different wave modes can be excited at arbitrary radius r. The common picture of wave field in this case presents the set of many wave modes localized in different areas of cylindrical plasma. The neighboring wave modes are overlapped. Therefore in the whole plasma area where conditions of instability for the waves of certain type are satisfied these waves consist of continuous wave field. In this cense this model is global.

Dynamics of formation and decay of the wave packets is a separate problem of our investigation. Naturally this problem is connected with form of dispersion relation $F(\omega,k)=0$ and the corresponding area of occurrence certain kind of waves. Fluctuation parameters in different conditions vary within wide range (frequencies, amplitude values, forms of fluctuations).

CONCLUSIONS

Numerical investigation of particle transport in non-uniform plasma with electrostatic waves is carried out. Diffusion is generated by drift in magnetic field, confined plasma and field of electrostatic oscillations, propagated in plasma. Diffusion passing perpendicular to magnetic field and has influence on energy and plasma confinement time. Results of the research may be used for method providing the suppression of transport processes and enhancement of confinement properties.

Mathematical models obtained can be used for full analysis of transport processes for wide class of magnetic confinement systems (spheromak, tandem mirror, gas dynamic trap, spherical tokamak). Including, diffusion and particle transfer properties. Moreover, last experimental data on the stellarator L-2M [12] shown a

good agreement between our theoretical predictions and field fluctuations observed in the experiments.

Instabilities with variable gradients are taken into account when the particle transport in plasma is considered. Calculations are carried out for the range of plasma parameters, reached in experiments. Non-local approach [13,14] is used in the analysis and dispersion relation is obtained. The possible suppression of drift wave turbulence is shown.

The main features of this model are taking into account complex field of drift waves propagating in plasma and analysis of motion of the particles interacting with field fluctuations.

The major conclusions of the study are summarized as follows:

1) model of anomalous transport in plasma with drift waves was developed in detail and main ideas of its are presented in this article;

2) plasma geometry/shape and particles energy (in the view of wave-particle interaction) have influence on the transport processes;

3) it is also found that the external electric field may be applied to control the particle transport and suppress the instablity.

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