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DISTRIBUTED VORTICITY AND DENSITY UNIFORMITY IN PLASMA LENS

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The influence of spatially distributed vorticity on the lifetime of discrete electron vortices in plasms lens is investigated analytically. The several mechanism is shown to lead to enhance a process of merging of discrete electron density nonuniformities and to crushing them.

Introduction

It is well known from numerous numerical simulations on computer (see, for example, [1]) and from experiments (see, for example [2]) that electron density nonuniformity in kind of discrete electron vortices are long-living structures in vacuum. But in experiments [2] a rapid re-organization of discrete electron density nonuniformity has been observed in the spatial distribution of vorticity in pure electron plasma when a discrete vortex has been immersed in an extended distribution of the background vorticity.

In plasma lens [3,4] for ion beam focusing a small-scale turbulence has been excited by unremovable gradient of external magnetic field. This turbulence is a distributed vorticity. It is shown theoretically in this paper that at certain conditions this ambient distributed turbulence could enhance a process of merging of discrete electron density nonuniformities and formation of cylindrically symmetrical distribution of electron density in the system. Also at certain conditions this turbulence could lead to crushing and smoothing of electron density uniformities.

Dynamics of vortices in distributed vorticity

Let us show that a vortex (i.e. an electron condensation) of large amplitude, appeared in distributed vorticity, propagates from the axis of the system. Also the distributed vorticity simultaneously leads to increasing of the vortex dimension, i.e. to decreasing of the electron plasma nonhomogeneity. Also we show that the vorticity provide a merging of neighboring vortices.

So, let us consider at first the behavior of a single vortex, enclosed to distributed vorticity. If vortex drifts on angle with velocity $V_{o\theta}=cE_{ro}/H_o$, then, determining the effect on it of the neighboring vorticity by effective frequency of collisions, ν_{ef}, from equation of movement of electrons one can obtain that the vortex propagates on radius from the axis of the system with radial velocity equal

$$V_r \approx \nu_{ef} e E_{ro}/m_e\omega^2_{ce} \qquad (1)$$

Here e, m_e, ω_{ce} are the electron charge, mass and cyclotron frequency.

The vorticity of the electrons is proportional to the density of perturbation. The two vortices rotate around their own centres and around each other. Because the stable electron radial distribution is with their density decreasing on radius, the two-vortex state is unstable. The instability development should lead to merging of two vortices, i.e. to decreasing of electron density non-homogeneity. In conditions of existence of distributed vorticity the instability is developed from finite initial amplitudes. Thus, distributed vorticity enhance the instability development and enhance the process of merging of two vortices.

Two charged electron vortices rotate around each other with some velocity $V_{1\theta} = cE_{ri}/H_o$, because they are in cross fields: in a longitudinal magnetic field H_o and radial electric field of each other $E_{ri} = 2N_ie/\Delta r$. Here N_i is the perturbation of electron density in vortex in comparison with the background electron density; Δr is the distance between vortices. Excitation of vorticity leads to propagation of two closed vortices from each other with velocity

$$V_{1r} \approx \nu_{ef} e E_{ri}/m_e\omega^2_{ce} \qquad (2)$$

Simultaneously each vortex is widen with velocity

$$V_\omega \approx eE_{ro}\nu_{ef}/m\omega_{ce}^2 \qquad (3)$$

Here $E_{ro} \approx 2N_ie/r_o$, r_o is the radius of the vortex. From expressions (2), (3) follows that the process of widening is more strong than their relative propagation. Thus the merging of two vortices is essential at distance between vortices equal to their radius

$$\Delta r \approx r_o \qquad (4)$$

Influence of distributed vorticity on electron density distribution

Because in experiments [2] the vortices have been merged, therefore, on long time merging of vortices can lead to formation of single vortex, symmetrical concerning an axis of a cylindrical system. Thus, cylindrically symmetrical distribution of electron density will be formed, not dependent on an angle.

Also nonlinear mode interaction, described by equation

$$\partial\Delta\varphi/\partial t=-(e/m_e\omega_{ce})\{\varphi, \Delta\varphi\}, \qquad (5)$$

leads to the extension of turbulent spectrum and therefore to crushing and smoothing of electron density non-uniformities. Here φ is the electric potential of perturbation.

Such properties of vortices, placed in excited vorticity, have been observed in experiments [2].

Thus the distributed vorticity at certain conditions decreases electron density unhomogeneities due to anomalous spatial transport and leads to relaxation of plasma to homogeneous state. But simultaneously the anomalous radial transport could lead to drop of electrons on the cylindrical wall. Nevertheless this would not lead to essential electron density decreasing at high secondary emission of electrons or at high intensity of ionization.

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