EFFECTIVE SEPARATOR FOR EXTRACTION OF HEAVY DROPS FROM PLASMA FLOW

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The behavior of the two plasma flows, propagating towards each other along axis of the cylindrically symmetrical cusp kind of the magnetic field, is considered. It is shown that for fixed plasma flow velocity and radius and for fixed radius of the magnetic field line curvature there is the most effective value of the magnetic field for the best control of plasma flows.

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INTRODUCTION

We consider the behavior of the two vacuum-arc plasma flows, propagating towards each other along axis of the cylindrically symmetrical cusp kind of the magnetic field. The cusp kind area is placed in cylindrical tube. We consider values of the external magnetic field in a range in which its effect on electrons is essential, and on positive metallic ions its effect can be not taken into account. We consider collisional case for the electrons. As a result of interaction of the plasma flow with the magnetic field, having cusp structure, a radial component of a polarizing electric field appears. Under action of this field the positive ions are displaced on radius in the direction of the cylindrical surface, resulting to increase of radius of the plasma flow.

The purpose of research is to obtain parameters of the system at which polarizing electric field is maximum and the flow of positive metallic ions on cylindrical surface is maximal.

Due to particle collisions, small magnetic field or oscillation excitation the electron dynamics is not controlled effectively by magnetic field. It is shown in this paper that for fixed plasma flow velocity and radius and also for fixed radius of magnetic field line curvature there is the optimum value of the magnetic field for the best control of the plasma flow. For the smaller and larger magnetic field values, the control of the plasma flow is essentially worse. For the small magnetic field the electrons are not magnetized. In this case the radial velocity of electrons is large due to collisions. For the larger magnetic field the azimuth field is excited and lead to anomalous transversal electron transport. The expression, which determines the connection of the optimum magnetic field value, velocity and radius of the plasma flow and radius of curvature of the magnetic field lines, is derived. For optimal parameters the azimuth field is not excited. Also for optimal parameters the polarizing electric field is maximum and the flow of positive metallic ions on cylindrical surface is maximal. The mechanisms of suppression of oscillated field excitation are also considered.

EFFECTIVE CONTROL OF PLASMA FLOW

Let us consider the dependence of the polarizing electric field E_p, which can be supported in the system, on value of the magnetic field H_o. We consider first of all the radial collisional transport of the electrons at value of the magnetic field, smaller the most effective one $H_o < H_{ef}$. Here under the most effective magnetic field we mean at which the azimuth asymmetry of the electron density [2, 3] is not excited in the system.

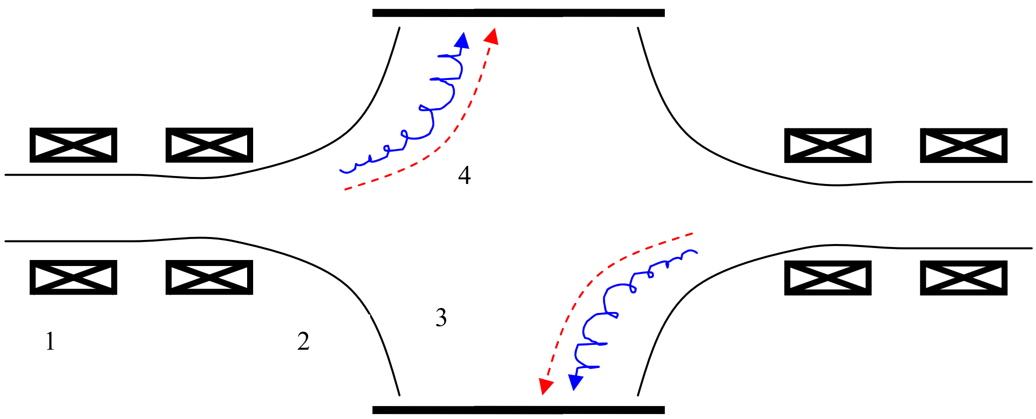

Fig. 1. The scheme of propagation of two plasma flows towards each other along axis of the cylindrically symmetrical cusp kind of the magnetic field. 1 is the magnetic coil, 2 is the magnetic field line, 3 is the processed cylindrical surface, 4 is the ion trajectory, solid arrow is the electron trajectory.

We use that the polarizing electric field is proportional to difference of ion and electron densities and difference of densities of ions and electrons falls with growth of the electron radial velocity $n_i - n_e \propto 1/V_r$. In the collisional case the radial electron velocity is equal to $V_r = eE_p\nu / m_e(\omega_{He}^2 + \nu^2)$. Here ν is the frequency of the electron collisions, E_p is the polarizing electric field, ω_{He} is the electron cyclotron frequency. From here, using that at H_{ef} the electron density is equal to n_{ef}, we find the electron density at anyone $H_o < H_{ef}$

$$n_e = n_i - (n_i - n_{ef})\sqrt{\frac{H_o^2 + \nu^2 m_e^2 c^2/e^2}{H_{ef}^2 + \nu^2 m_e^2 c^2/e^2}}$$

It is visible, that $n_e = n_{ef}$ at $H_o = H_{ef}$ and n_e decreases with growth H_o at $H_o < H_{ef}$.

The excitation of azimuth asymmetry of the electron density is described by the following dispersion ratio

$$1 - \alpha_-^{(i)} - \alpha_+^{(i)} + (\omega_{pe}/\omega_{He})^2 (k_\theta \beta/k^2) = 0,\ \alpha_\pm^{(i)} = \omega_{pi}^2/(\omega \pm k_z V_{pi})^2,$$

$$\beta = (\omega - k_\theta\, m_i V_{pi}^2/R m_e \omega_{He})^{-1}\, d\omega_{He}/dr$$

similar to [3]. Here ω_{pi} is the plasma ion frequency, k_z and k_θ are the longitudinal and azimuth wave vectors, V_{pi} is the plasma flow velocity, R is the radius of curvature of magnetic field lines, m_e and m_i are the masses of the electrons and ions.

At excitation of azimuth asymmetry of the electron density their transversal transport becomes more so they are taken by positive ions more easy across the magnetic field amplifies and they obey worse a configuration of the magnetic field. Approximately we count the velocity of electron transversal transport V_r proportional to the growth rate of the instability development γ, i.e. the intensity of the azimuth electron asymmetry excitation. As at the parameters, close to the most effective parameters, the slow azimuthally asymmetrical perturbations of the electron density are excited γ is determined by their growth rate γ_{nm} [3]. Then we approximately derive

$$n_e - n_i \propto 1/V_r \propto 1/\gamma_{nm},\ n_e \sim 1/V_r \sim 1/\gamma_{nm} \sim [\ell_\theta \Delta n/H_o]^{-1/3},$$

$$\ell_\theta \sim [(1-\eta)(\partial_r(1/\omega_{ce})/V_{o\theta}]^{1/2},\ V_{o\theta} \sim \Delta n/H_o.$$

Then we have $n_e \sim H_o^{1/3}/[(1-\eta)n_e\Delta n]^{1/6}$. We take into account, that $\eta = \eta_{ef}(\Delta n/\Delta n_{ef})(H_{ef}/H_o)^2$, $\eta_{ef}=1$. $\Delta n \equiv n_{oe} - n_{oi}$. Then we have

$$n_e \sim H_o^{1/3}/\{n_e \Delta n[1-(\Delta n/\Delta n_{ef})(H_{ef}/H_o)^2]\}^{1/6}.$$

One can see, the more H_o exceeds H_{ef}, n_e is less.

For $H_o > H_{ef}$ ($H_o >> H_{ef}$) the motionless on the azimuth (moving on the azimuth with the large angular speed) azimuth asymmetry of the plasma density is excited. Hence, the density, average on time, of the plasma flow on the cylindrical surface is strongly non-uniform (uniform) on the azimuth.

For the most effective magnetic field at which there is no anomalous transversal transport we have similar to [3]. The azimuth asymmetry is not excited when plasma particle bunches can not be formed

$$1=\frac{4}{r_p\omega_{Hi}^2}\left[\frac{V_i^2}{R}\left(1+\frac{\nu^2}{\omega_{Hi}^2+\nu^2}\right)-\frac{\partial_r(T_in_i)}{m_in_i}\right],\ \frac{V_i^2}{R}=\frac{eE_p}{m_i}.$$

ν is the ion collision frequency.

The azimuth drift velocity $V_{\theta o}$ of the electrons in non-uniform magnetic field $\vec{H}_o$ and in crossed magnetic and electric field of polarization $\vec{E}_p$ equals [4]

$$\vec{V}_{\theta o}=c\left[\vec{E},\vec{H}_o\right]/H_o^2+V_z^2\left[\vec{H}_o,\left(\vec{H}_o\vec{\nabla}\right)\vec{H}_o\right]/\omega_{He}H_o^3+V_\perp^2\left[\vec{H}_o,\vec{\nabla}H_o\right]/2\omega_{He}H_o^2 .$$

$V_{\theta o}\approx m_iV_i^2/Rm_e\omega_{He}$. One can show, that the ratios of the first member in the right part to the second and third are approximately equal to $(V_i/V_s)^2$. Here V_s is the ion-acoustic velocity. Thus, if the plasma flow velocity V_i is less (more) than V_s, then the drift velocity in a non-uniform magnetic field is more (less) than velocity of drift in the crossed fields. In other words, if the energy of the plasma flow $m_iV_i^2/2$ is less (more) than the electron temperature $m_iV_i^2/2<T_e$ ($m_iV_i^2/2>T_e$), then the drift velocity in a non-uniform magnetic field is essential (is insignificant).

For the effective magnetic field for $V_i>V_s$ we have

$$\omega_{Hi}=\sqrt{\left(\alpha-\nu^2\right)\left[0.5+\sqrt{0.25+\beta\nu^2/\left(\alpha-\nu^2\right)^2}\right]},$$

$$\alpha=\frac{4}{r_p}\left(\frac{V_i^2}{R}-\frac{\partial_r(T_in_i)}{m_in_i}\right),\ \beta=\alpha+\frac{4V_i^2}{r_pR}.$$

CONCLUSION

Thus, the value of the most effective magnetic field has been derived, at which the best control of the plasma flow by the magnetic field is realized.

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