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Electromagnetic Field Effect on Impurity Ion Transport in Helical Plasma

Oleksandr Yu. Antufyev[1], Alexander A. Shishkin[2], Zhanna S. Kononenko[1]

[1] *Kharkov V.N. Karazin National University, Kharkov, Ukraine*

[2] *Institute of Plasma Physics, National Science Center "Kharkov Institute of Physics and Technology", Kharkov, Ukraine*

The processes of resonant interaction of the charged particle with the alternating electric field are covered in numerous experimental and theoretical works. Detrapping processes under the alternating electric field with the frequency, close to the bounce frequency of the trapped particle is studied in theoretical works. The effects of wide-spectrum noise signal on trapped particles are considered experimentally on "Saturn" stellarator and "VINT-20" torsatron. The processes of detrapping under the effect of high-frequency electric field with changeable frequency are considered also by numerical simulations [1].

Heavy impurity ion transport is considered in the vicinity of two adjacent rational magnetic surfaces in the helical plasma under the drift-wave-like potential. The trajectories of the **passing particles** can form the rational drift surfaces. If there are some adjacent rational drift surfaces with the drift rotational transform $\iota^* = n/m$, $\iota^* = n'/m'$, $\iota^* = n''/m''$, then the magnetic perturbations with the wave numbers (m,n), (m',n'), (m'',n'') can lead to some families of drift islands. Overlapping of the adjacent resonance structure is the reason for the stochasticity of the particle trajectories. If a particle trajectory passes through the set of perturbations this test particle can escape from the center of the confinement volume to the periphery. The **helically trapped particles** with the orbits of the helical banana-type can be transferred into the "toroidally trapped" particles under the effect of this electromagnetic field.

In this paper it is shown, that passing impurity particle becomes trapped under the drift wave electric field. Similarly to the estafette of drift resonances [2], the impurity ion feels the drift wave electric field sequentially and moves outside of the confinement volume and escapes. Although the backward impurity transition from the trapped state into the passing one is possible, the penetration of the impurity into the core plasma is not expected. It is important to understand the conclusive result of impurity transport.

The test particle orbits are studied by the numerical integration of Newton-Poisson equation system for the charged particle in the electromagnetic field. As the test particle the tungsten ion is taken.

Models and basic equations:

The confining magnetic field ($\mathbf{B} = \nabla\Phi_M$) in the magnetic trap is simulated with the use of magnetic field potential

$$\Phi_M = B_0\left(R\varphi - \frac{R}{m}\sum_n \varepsilon_{n,m}\left(r/a\right)^n \sin(n\vartheta - m\varphi) + \varepsilon_{1,0} r \sin\vartheta\right), \quad (1)$$

where r, ϑ, φ are the radial, poloidal and toroidal coordinates correspondingly, B_0 is the magnetic field magnitude at the magnetic axis, R and a are the major and minor radii of the torus, l is the number of helical winding poles, m is the number of magnetic field periods along the torus, $\varepsilon_{n,m}$ are the coefficients of appropriate harmonics of the magnetic field. For our consideration we take the parameters of the torsatron URAGAN-3M, namely, B_0=1.2 T, R=100 cm, a=27.5 cm, l=3, m=9, $\varepsilon_{1,0}$=0.275, $\varepsilon_{3,9}$=0.65, $\varepsilon_{4,9}$=0.032, $\varepsilon_{2,9}$=-0.056. The magnetic field absolute value is given by $B \approx B_\varphi$. This magnetic field model simulates a set of closed magnetic surfaces. The magnetic surfaces cross-sections are presented on the Fig. 1.

The electric field is derived from the following drift wave potential expression [3]:

$$\Phi_E(r,\vartheta,\varphi) = \Phi_{E0}\exp\left[-\sigma_I (r-r_0)^2/2\right]\cos\left[-\sigma_R (r-r_0)^2/2 + l\vartheta + m\varphi\right], \quad (2)$$

and is simulated with the components E_r, E_ϑ, E_φ in toroidal coordinates.

The charged particle motion in the electromagnetic field is studied by the numerical integration of the Newton-Lorentz equation:

$$M\frac{d\mathbf{v}}{dt} = Ze\mathbf{E} + \frac{Ze}{c}\left[\mathbf{v},\mathbf{B}\right], \quad (3)$$

where M - mass, $\mathbf{v}$ - velocity, Z - charge number of the test particle. The tungsten ion with Z=30 and energy 1 keV is taken as the test particle.

Results of the numerical study:

The start position and the initial pitch of the test particle are chosen so that it is passing without the influence of the drift wave electric field. The passing test particle orbit is presented on the Fig. 2. The drift wave potential is simulated to have two items:

$$\Phi_E(r-r_{01}, r-r_{02}) = \Phi_{E1}(r-r_{01}) + \Phi_{E2}(r-r_{02}). \quad (4)$$

Thus the radial distribution of the electric field has two “peaks” at the radius r_{01}=13 cm and r_{02}=16 cm. The test particle moves in the confinement volume under electric field. It is necessary to point out that the effect of these two potentials taken separately does not lead to particle escape, but only to its transition into trapped state. Particle orbits, corresponding to these cases, are presented on the Fig. 3 and Fig. 4.

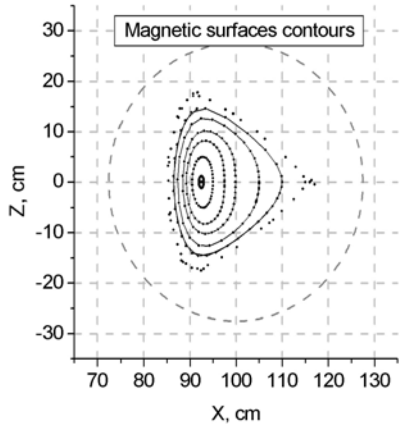

Fig. 1. Magnetic surfaces cross-sections.

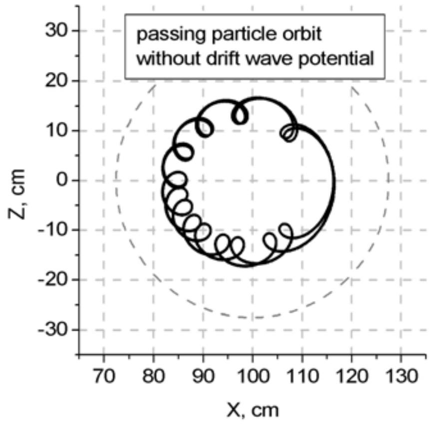

Fig. 2. Passing test particle orbit.

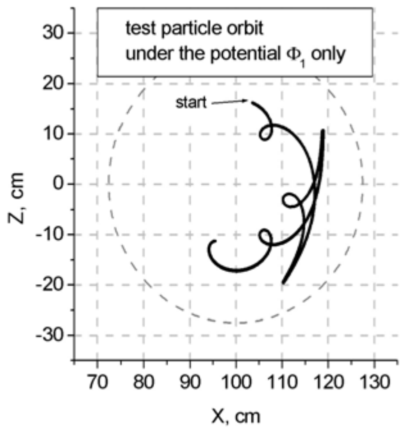

Fig. 3. Test particle orbit under the potential $\Phi_1(r - r_{01})$ taken separately.

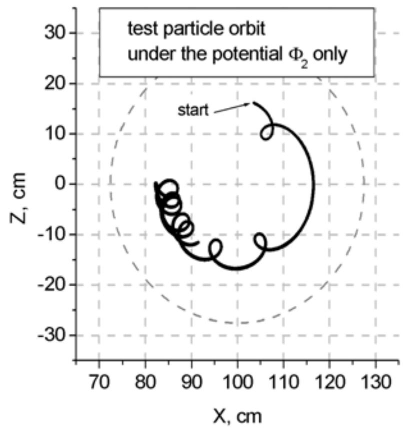

Fig. 4. Test particle orbit under the potential $\Phi_2(r - r_{02})$ taken separately.

If the radial coordinate (position) of the test particle is close to r_{01} then it feels the effect of the electric field potential $\Phi_1(r - r_{01})$ and transits into the trapped state. As the test is trapped, it deviates from the initial magnetic surface on a remarkable distance and comes under the influence of the electric field potential $\Phi_2(r - r_{02})$. The effect of this potential on the test particle is that the test particle escapes the confinement volume. The vertical cross-section of the escaping particle orbit is shown on the Fig. 5. The top view of the particle orbits is presented on the Fig. 6. Dotted line corresponds to the passing particle orbit and solid line indicates the orbit of the escaping test particle under the drift-wave electric field.

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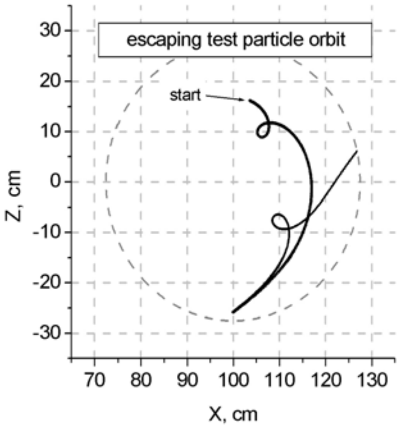

Fig. 5 Effect of two drift-wave potentials on the test particle orbit.

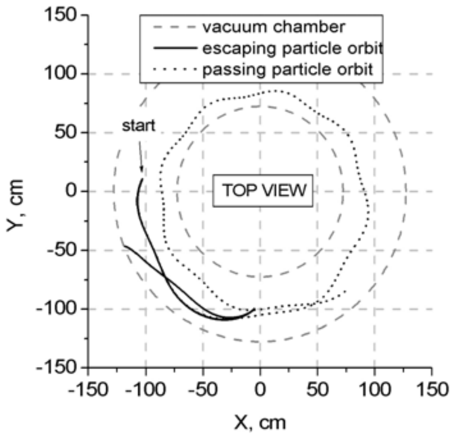

Fig. 6. Top view of the passing (dot) and escaping (solid) test particle orbits.

In the **conclusion** we would like to stress on the possibility of the heavy impurity removal from the helical plasma periphery with the help of drift-wave electric field. The impurity ion transits from passing state into the trapped one under the effect of the electric field and escapes from the magnetic volume due to the natural drift in the inhomogeneous magnetic field.

Acknowledgements

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