RADIO FREQUENCY CONTROL of PARTICLE DETRPPING / RETRAPPING PROCESS in a STELLARATOR TYPE DEVICE

Alexander A. Shishkin, Igor' K.Tarasov and Vladimir D.Fedorchenko

Institute of Plasma Physics, National Science Center "Kharkov Institute of Physics and Technology", Academicheskaya str.1, Kharkov, 61108, Ukraine
and
Kharkov "V.N. Karazin" National University, Svobody sqr. 4, Kharkov, 61077, Ukraine

The possibility to study experimentally the effect of AC electric field on the transit particles is considered on the example of the small stellarator device. This study is important for the development of scenario for the ambipolar electric field control in plasma due to injection of the particles into plasma core in the fusion devices.

MOTIVATION OF STUDY

Transit particles are the particles that transfer from the different states from passing to trapped in the interaction with the waves – static such as the modulated in the space magnetic filed and usual electromagnetic waves. They are very interesting subject of study and very important one for stellarator type devices. At the beginning of the stellarator study transit particles were considered as the obstacle on the way of the plasma confinement improving and many efforts were made to decrease the amount of particles with transit orbits and even eliminate the transit particles due to optimization the magnetic configuration. However, later [1,2] it was found that these particles could be used to control radial electric field in plasma in order to improve the confinement. Injected outside of the last closed magnetic field these electrons being trapped with the helical magnetic field move across the magnetic surfaces and then transfer into particles toroidally trapped in the center of the magnetic confinement volume and stay there for a long time. They can affect the radial electric field in plasma. The use of AC electric field can prolong the time of the staying into the center of confinement volume and increase the fraction of particles with the transit orbits [1,2]. This physics mechanism can be used to remove the "cold" alpha particles and impurity ions from the plasma center to the periphery of plasma and confinement volume [3,4]. Therefore **transit orbits** without AC electric field and **transit orbits *with AC electric field*** should be studied experimentally.

Particle detrapping / retrapping process without AC electric field applied externally was studied experimentally on the Heliotron D device of the torsatron type [5]. It was shown that the electrons with the transit orbits of injected outside the last closed magnetic surface can penetrate into the center of the magnetic field confinement volume as it is predicted in theory [2]. Next step in the study of the particle detrapping / retrapping process can be carried out *with* AC electric field.

The experimental study can be carried out on the setup with the 16 toroidal coils and helical field coils [6]. The magnetic field intensity is up to 1 kGs. The helical magnetic field is produced with the l=2 and m=8 stellarator type helical windings. The small and large radii of the helical coils are 6 cm and 42 cm correspondingly. The rotational transform at the boundary of the plasma column $\iota(a_p)$ is equal to 0.02. Electrons with the energy up to 1 keV are confined in such magnetic configuration.

The calculations of the drift trajectories in this configuration show the possibility to observe the transit orbits under the special range of the pitch velocity $V_\parallel / V$ and angular variable ϑ_{start} values. The effect of AC electric field in this device is being studied numerically now. In future the experimental results can be applied for the torsatron Uragan-2M because of the similarity of the pitch angle of the helical windings.

TRANSIT PARTICLES *without* AC ELECTRIC FIELD

Model of the magnetic field.

Magnetic field in the stellarator mentioned above can be described as follows

$$B_r = B_0(-1)\frac{Rl}{ma}\varepsilon_{l,m}\left(\frac{r}{a}\right)^{l-1}\sin(l\vartheta - m\varphi),$$

$$B_r = B_0(-1)\frac{Rl}{ma}\varepsilon_{l,m}\left(\frac{r}{a}\right)^{l-1}\cos(l\vartheta - m\varphi),$$

$$B_\varphi = B_0\left[1+\varepsilon_t\frac{r}{a}\cos\vartheta + \varepsilon_{l,m}\left(\frac{r}{a}\right)^{l}\cos(l\vartheta - m\varphi\right].$$

Here r, ϑ, φ are quasi-cylindrical coordinates connected with the circular axis of the torus; the amplitudes of the magnetic field toroidal and helical in-homogeneity are the following: ε_t=1/7 and $\varepsilon_{l,m} = \varepsilon_{2,8} = 0.03$. The magnetic surfaces are shown in Figure 1 and Figure 2 as the background of the trajectories of test particles.

Main equations. In order to study particle orbits we use the guiding center equations

$$\frac{d\mathbf{r}}{dt} = V_\parallel\frac{\mathbf{B}}{B} + \frac{c}{B^2}[\mathbf{E}\times\mathbf{B}] + \frac{M_j c\left(2V_\parallel^2 + V_\perp^2\right)}{2e_j B^3}[\mathbf{B}\times\nabla B],$$

$$\frac{dW}{dt} = e_j\mathbf{E}\frac{d\mathbf{r}}{dt} + \frac{M_j V_\perp^2}{2B}\frac{\partial B}{\partial t},$$

$$\frac{d\mu}{dt} = 0,$$

which are the common well known tool for the study of particle confinement (see, for example [2]). Here $\mathbf{r}$ is the radius-vector of the particle guiding center trajectory; $\mathbf{B}$ is the magnetic field, $\mathbf{E}$ is the electric field, $V_\parallel$ and $V_\perp$ are the parallel and the perpendicular velocities of the

particle, M_j and e_j are the mass and the c
particle; W and μ are the kinetic energy and magnetic moment of the particle: $\mu = \dfrac{M_j V_\perp^2}{2B}$.

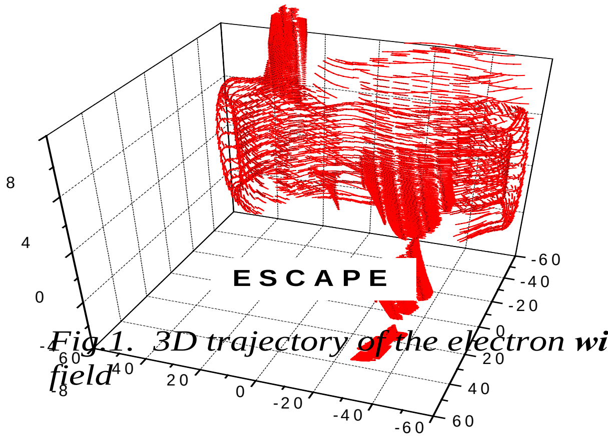

*Fig.1. 3D trajectory of the electron **without** AC electric field*

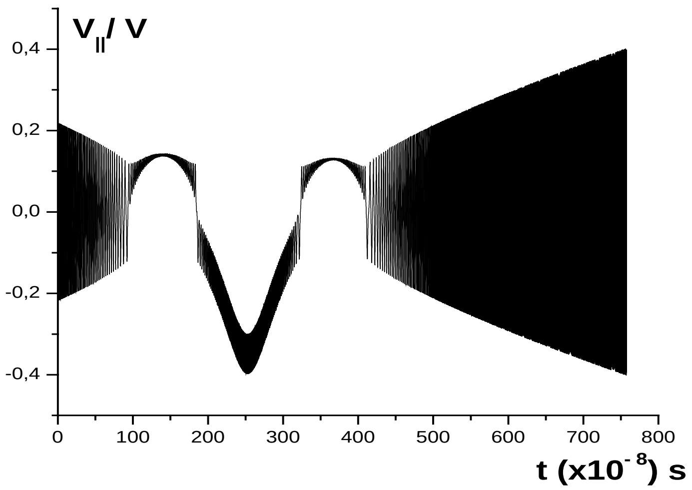

*Fig.2. $V_\parallel / V$ as the function of time **without** AC electric field*

Particle orbit study. For the test particles the launching parameters are chosen in such way that the particle transforms from the helically trapped one into the toroidally one. These are so called the particles which belong to the loss cone. In figures below we can see typical trajectory in 3D real space (Figure 1) and velocity as the function of time (Figure 2). The starting point coordinates are the following r_0=8.868170, ϑ_0= -4.712859, φ_0 =37.017930; the launching velocity pitch $V_{\parallel 0}/V$ = -0.1777049. The parameters are pointed here exactly because as it is known the transition of particle depends strongly on the launching poloidal angle and velocity pith [2-5]. There is rather narrow ranges of both parameters: poloidal angle and pitch velocity, - when transition particle and penetration of these particles from the outside of the confinement volume into inside it can occur. From the figures mentioned above we see the time

interval when the particle is helically trapped then becomes toroidally trapped near the circular axis and th
is re-trapped again and escapes from
volume. The time of the staying in the t
state is near 50×10^{-6} s.

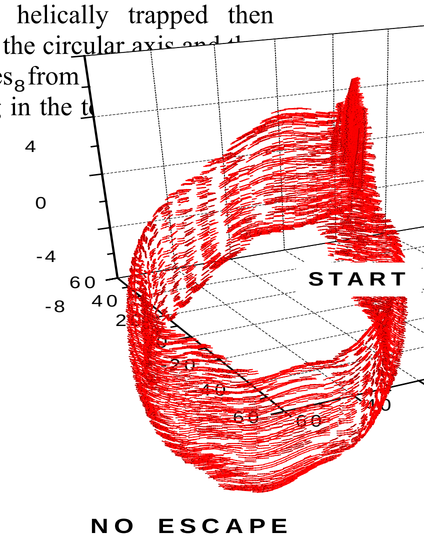

*Fig.3. 3D trajectory of the electron **with** AC el*

TRANSITION OF PARTICLES *with* ELECTRIC FIELD

Model of the AC electric field $\tilde{E}_\varphi$.

To affect the electron motion we use the AC el in the form

$\tilde{E}_\varphi = \tilde{E}_{\varphi 0} \cos(l\vartheta - m\varphi)\cos(\Omega_E t + \delta_{l,m})$.

In our study the AC electric field frequency is c helical field bounce frequency of the ($\Omega_E \approx \omega_{hb}$). We assume that the electric fi the particle motion not from the beginning bu certain time $t \geq t_{\tilde{E}_\varphi}$.

Results of modelling

For our case this time is close to the moment re-trapping in the helical magnetic well. The tra the particle under AC electric field is shown in This time of the AC electric field switching on Figure 4. The particle does not become helical again as it is without AC electric field. Th remains in the center of the confinement volume

DISCUSSION AND CONCLUSIO

1. We see the possibility to observe the tra particles from the state of helically trapped par the toroidally trapped ones ***under the high–*** ***electric field*** effect. This effect can be studi stellarator type device with the small pitc windings (with the small angle of the helical inclination).
2. Under the increasing the existing magnetic fie times (up to 4 kG) the effect becomes more noti
3. Sometimes the question arises about the vali guiding center equations for the study of AC ele on the particle motion. The best way to co validity is to illustrate the same effect with the i of the Newton – Lorentz equations. Such study carried out and the results will be published in t future.

4. Because of similarity of the helical winding pitch conductors in the stellarator device considered here and Uragan-2M the experimental study on small device can be helpful for the fusion devices of medium and large scale.

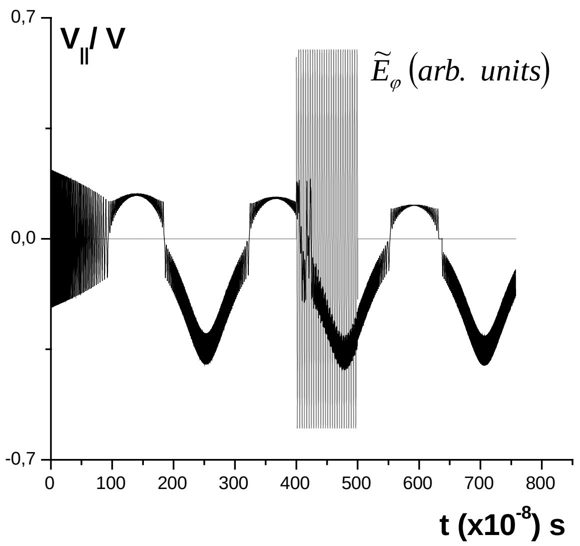

Fig.4. $V_{||}/V$ *and AC electric field as the functions of time* ***with*** *AC electric field*

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ВЧ КОНТРОЛЬ ПРОЦЕССА «ЗАХВАТ / ОСВОБОЖДЕНИЕ» ЧАСТИЦЫ В СТЕЛЛАРАТОРЕ

Александр Шишкин, Игорь Тарасов и Владимир Федорченко

Рассмотрена возможность экспериментального изучения влияния переменного электрического поля на частицы с переходными траекториями на примере небольшого прибора стеллараторного типа. Это изучение важно для развития сценария контроля амбиполярного электрического поля в плазме в термоядерных системах, чего можно достичь инжекцией частиц в центр плазмы.

ВЧ КОНТРОЛЬ ПРОЦЕСУ «ЗАХВАТ / ОСВОБОЖДЕНИЕ» ЧАСТИНКИ У СТЕЛАРАТОРІ

Олександр Шишкін, Ігор Тарасов та Володимир Федорченко

Розглянута можливість експериментального вивчення впливу змінного електромагнітного поля на частинки з перехідними траєкторіями на прикладі невеличкого пристрою стелараторного типу. Таке вивчення важливе для розвитку сценарію контролю амбіполярного електричного поля в плазмі в термоядерних системах за допомогою інжекції частинок у центр плазми.