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CONTROL OF ELECTRON AND ION ENTRAPPING / DE-TRAPPING IN HELICAL MAGNETIC FIELD WITH USE OF AC FIELD EFFECT

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Here it is shown that AC field $\widetilde{\mathbf{E}}$ can be used for the effect on the electron entrapping/ de-trapping process to improve the penetration of injected particles in the core of the confinement volume of the heliotron type device. Slowly changing in time a helical magnetic field transform the resonant passing ion (an ion that forms the drift island) into the helically trapped particle and causes the escape of the helically trapped ion from the confinement volume. Slowly varied in time AC field, which effects the entrapping / de-trapping process of the particle, can be produced with the helical conductor current varied in time.
KEY WORDS: helical magnetic field, particle transition processes, magnetic field perturbation, AC field

MOTIVATION OF STUDY

Transit particles are the particles which transfer from the state of passing particle into the helically or toroidally trapped one in the helical magnetic field in the toroidal traps and vice versa. These particles are present in stellarator type devices. At the beginning of the stellarator study transit particles were considered as the obstacle on the way of plasma confinement improving because of significant contribution in the transport ("super-banana" trajectories). Many efforts were made to decrease the amount of particles with transit orbits and even eliminate particle transition by optimization of the magnetic configuration. However, later [1-3] it was found that these particles could be used to control a radial electric field in plasma in order to improve the confinement. Ions or electrons, which are injected from outside of the last closed magnetic surface are trapped on the helical inhomogenity of magnetic field. These particles move across the magnetic surfaces and then transfer into the particles which are 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 in the center of confinement volume and increase the fraction of particles with the transit orbits. This physics mechanism can be used to fill the magnetic trap with electrons. This mechanism can be also used for the technology goals to transport the ions produced with the ion gun to the space place outside the last closed magnetic surface.

Therefore **transit orbits** without AC electric field and **transit orbits** ***with AC electric field*** should be studied experimentally.

Particle entrapping / de-trapping process without AC electric field was studied experimentally on the Heliotron DR device of the torsatron type [4]. It was shown that the electrons with the transit orbits injected from outside of the last closed magnetic surface can penetrate into the center of the magnetic field confinement volume as it was predicted in theory. After the successful observation of the transition of the helically trapped particle into the toroidally trapped particles and passing particles on the helical device Heliotron DR [4] next step in the study of the particle entrapping / de-trapping process can be carried out *with* AC electric field.

The calculations of the drift trajectories in this configuration show the possibility to observe the transit orbits within the special range of the pitch $V_{\|}/V$ and angular variable ϑ_{start} values. The results of the effect of AC electric field in this device studied numerically are given now.

Magnetic system of Heliotron DR [5] device is produced by three items. The first item is the toroidal solenoid of $N = 30$ coils. The second item consists of $l = 2$, $m = 15$ helical field coils. And the third one include two additional helical windings, which can produce the perturbing magnetic field with "wave" numbers $m_p / n_p = 2/3$ and $m_p / n_p = 1/1$. The most important property of this device is the possibility to supply all these coils independently.

The helical winding with "wave" numbers $m_p / n_p = 1/1$ can be used as the exciting system which can produce the necessary Fourier component $m = n = 1$ of AC field $\widetilde{\mathbf{E}}$.

Such experiment is proposed to be carried out in the vacuum configuration in order to compare the results of AC electric field effect on the transition process: particle transition from the helically trapped state into the toroidally trapped or passing one *without* AC field effect [4] and *with* it.

BASIC EQUATIONS AND THE MAGNETIC AND ELECTRIC FIELD MODELS

Basic Equations

Guiding center equations [6] are used for our consideration:

$$\frac{d\mathbf{r}}{dt} = V_{II}\frac{\mathbf{B}}{B} + \frac{c}{B^2}[\mathbf{E}\times\mathbf{B}] + \frac{M_j c(2V_{II}^2 + V_{\perp}^2)}{2ZeB^3}[\mathbf{B}\times\nabla B],$$
$$\frac{dW}{dt} = Ze\mathbf{E}\frac{d\mathbf{r}}{dt} + \frac{M_j V_{\perp}^2}{2B}\frac{\partial B}{\partial t}, \qquad (1)$$
$$\frac{d\mu}{dt} = 0 .$$

Here $\mathbf{r}$ is the radius-vector of the particle guiding center, $\mathbf{B}$ is the magnetic field, $\mathbf{E}$ is the electric field, $V_{\|}$ and $V_{\perp}$ are the parallel and perpendicular velocities, M_j and Z are mass and charge number of the particle, e is the elementary charge, W is the kinetic energy and μ is the magnetic moment of the particle ($\mu = M_j V_{\perp}^2 / 2B$).

Main magnetic field

The magnetic configuration of the heliotron device is modeled here with the use of the scalar magnetic potentials Φ and Φ_p, where the main magnetic field $\mathbf{B} = \nabla\Phi$ and the perturbing magnetic field $\mathbf{B}_p = \nabla\Phi_p$.

The main magnetic field potential is taken in the form

$$\Phi = B_0\left[R\varphi - \frac{R}{m}\sum_n \varepsilon_{n,m}(r/a_h)^n \sin(n\vartheta - m\varphi) + \varepsilon_{1,0} r\sin\vartheta\right]. \qquad (2)$$

where B_0 is the magnetic field at the circular axis, R and a_h are the major and minor radii of the helical winding; the coordinates r, ϑ, φ are connected with the circular axis of the torus, r is the radial variable, ϑ and φ are the angular variables along the minor and major circumference of the torus, ϑ increases in the direction opposite to the main normal to the circular axis of the torus. Metric coefficients are the following: $h_r = 1$, $h_\vartheta = r$, $h_\varphi = R - r\cos\vartheta$. m is the number of the magnetic field periods along the torus, l is the helical winding pole number. The index n assumes the values $n = l$, $l-1$, $l+1$. $\varepsilon_{n,m}$ are the coefficients of the harmonics of the magnetic field. The results presented here are obtained for the following parameters: $l = 2$, $m = 15$, $B_0 = 0.05$ T, $R = 90$ cm, $a_h = 13.5$ cm; the values of $\varepsilon_{n,m}$ are taken in such a way that the magnetic surfaces, the magnetic field modulation along the force line and other properties coincide with the results of Ref. [4,5]. For the configuration with the inward shift of the magnetic axis the parameters are $\varepsilon_{2,15} = 0.395$, $\varepsilon_{1,0} = 0.00375$.

The perturbing magnetic field

The perturbing magnetic field considered here is given with the following components:

$$B_{rp} = (-1)B_0\frac{Rn_p}{m_p a_h}\varepsilon_{n,m,p}\cos(\Omega t)(r/a_h)^{n_p-1}\sin(n_p\vartheta - m_p\varphi + \delta_{n,m,p}), \qquad (3.1)$$

$$B_{\vartheta p} = (-1)B_0\frac{Rn_p}{m_p a_h}\varepsilon_{n,m,p}\cos(\Omega t)(r/a_h)^{n_p-1}\cos(n_p\vartheta - m_p\varphi + \delta_{n,m,p}), \qquad (3.2)$$

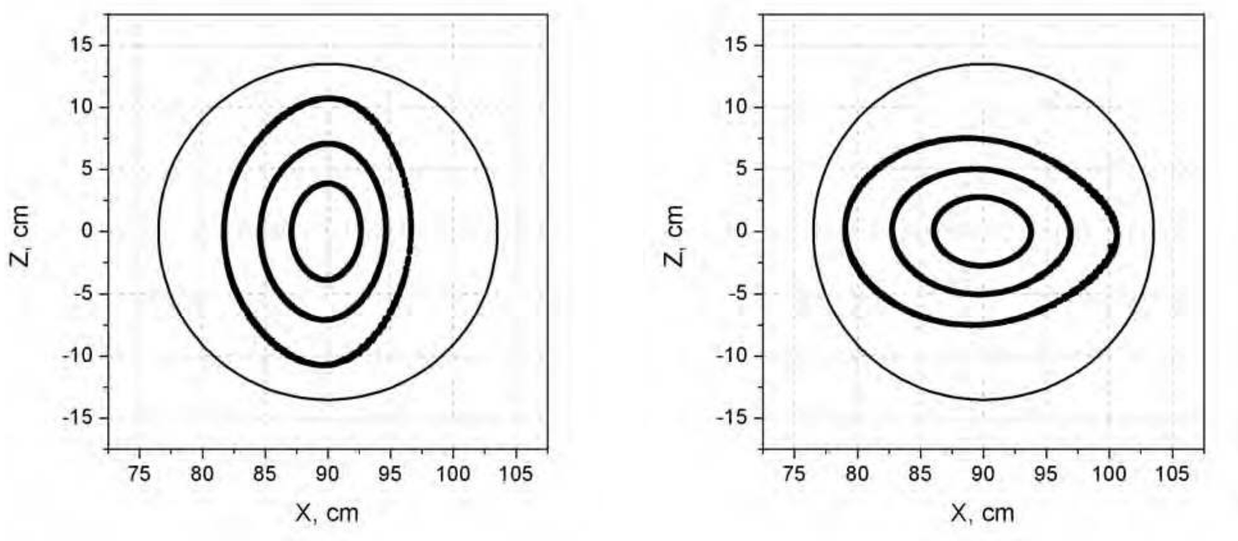
$$B_{\varphi p} = B_0\varepsilon_{n,m,p}\cos(\Omega t)(r/a_h)^{n_p}\cos(n_p\vartheta - m_p\varphi + \delta_{n,m,p}). \qquad (3.3)$$

The “wave numbers”, amplitude and phase values of the perturbing magnetic field are the following: m_p=1 n_p=1; $\varepsilon_{1,1,p}$= 0.00001, $\delta_{n,m,p} = \pi/2$.

Magnetic surfaces

The magnetic surfaces at the beginning and at one half-period of the magnetic field are shown on Fig. 1. There are no islands, which usually appear on the place of the magnetic surfaces with rotational transform $\iota = 2/3$ because the corresponding perturbation is absent (switched off). The magnetic surface with $\iota = 1/1$ is absent under the chosen parameters of the magnetic configuration. The rotational transform on the last closed magnetic surface is approximately

$\iota \approx 0.844$. It is important to underline this fact because we use here $m_p / n_p = 1/1$ helical winding. The magnetic field perturbations with the corresponding "wave" numbers do not affect the magnetic configuration.



a b

Fig.1. Magnetic surfaces under the perturbation with the wave numbers $n_p = 1$, $m_p = 1$ at two vertical cross-sections.
a - at the beginning of the magnetic field period, b - at the half-period of the magnetic field period.

AC Electric Field Model

Electric field has the following components, which satisfy Maxwell's equations

$$\tilde{E}_r = \sum_{l_W, m_W} \tilde{E}_{l_W, m_W} \Omega_W \, (r/a)^{lw-1} \sin(\Omega_W t) \sin(l_W \vartheta - m_W \varphi + \delta_W), \tag{4.1}$$

$$\tilde{E}_\vartheta = \sum_{l_W, m_W} \tilde{E}_{l_W, m_W} \Omega_W \, (r/a)^{lw-1} \sin(\Omega_W t) \cos(l_W \vartheta - m_W \varphi + \delta_W), \tag{4.2}$$

$$\tilde{E}_\varphi = \sum_{l_W, m_W} \tilde{E}_{l_W, m_W} \Omega_W \, (r/a)^{lw} \sin(\Omega_W t) \cos(l_W \vartheta - m_W \varphi + \delta_W). \tag{4.3}$$

Here the amplitude of the electric field is connected with the amplitude of the helical perturbing field in the following way:

$$\tilde{E}_{l_W, m_W} = \frac{B_0}{c} \varepsilon_{m,n,p} \frac{R}{m_p} \left(1 + \frac{m_p a}{R n_p} \right). \tag{4.4}$$

For the results below the parameters are taken as follows: $l_W = 1$, $m_W = 1$, $\delta_W = \pi / 2$; The wave numbers are the same as of the helical perturbation field. The value of Ω_W is close to Ω_{BOUNCE} ($\Omega_W \approx \Omega_{BOUNCE}$). The change of the relation between Ω_W and Ω_{BOUNCE} in time in the process of the particle motion is shown on Fig. 3b with $V_\parallel / V$ in black and $\sin(\Omega_W t)$ in grey. The results given below are obtained for the following parameters: $l_W = 1$, $m_W = 1$, Ω_W is close to Ω_{BOUNCE} for the electrons. The relation between Ω_W and Ω_{BOUNCE} is seen below on figures with the pitch velocity and electric field dependence on time.

PENETRATION INSIDE THE CONFINEMENT VOLUME OF THE ELECTRONS INJECTED FROM OUTSIDE THE LAST CLOSED MAGNETIC SURFACE

Choice of the starting conditions of electrons

Electron starting points are outside the last closed magnetic surface. Particle trajectory is shown on the background of the cross-sections of the magnetic surfaces at the beginning and at one half-period of the magnetic field. The energy of an electron $W = 100$ keV. The starting point coordinates are chosen in the following way: $r_0 = 11.4$ cm, $\vartheta_0 = 12.3$ radian, $\varphi_0 = 1.3$ radian and parallel velocity to total velocity ratio (pitch-velocity) $V_\parallel / V \big|_0 = -0.377$. The starting coordinates and starting pitch velocity parameter $V_\parallel / V$ are found with the use of the reversed trajectory principle. At first we follow the trajectory of the particle starting in the center of the confinement volume till it intersects the last closed magnetic surface. At that moment we fix the coordinates and $V_\parallel / V$ value. In such way we find the place where it is necessary to deposit the electron gun and the $V_{\|}/V$ starting value of the electrons emitted with the gun. The particle starts as the trapped one between the bumps of the helical magnetic field. If the AC field is tuned off, then the particle is the transit one. The turning points are seen in the vertical plane (Fig.2a) and the horizontal plane (Fig.2b) of the test particle orbit. The particle starts outside the last closed magnetic surface and its orbit can be conventionally divided onto three parts:

1) Test particle moves along the banana-like orbit, being helically trapped, from the start point of approx. X=80 cm, Z=-3.5 cm, see Fig 2a to the transition point of approx. X=92 cm, Z=5 cm. This corresponds to a fin-shaped area at approx. X=0 cm and Y=60 cm on the Fig 2b and time period from 0 to $t = 230 \cdot 10^{-7}$ seconds on the Fig 2c.

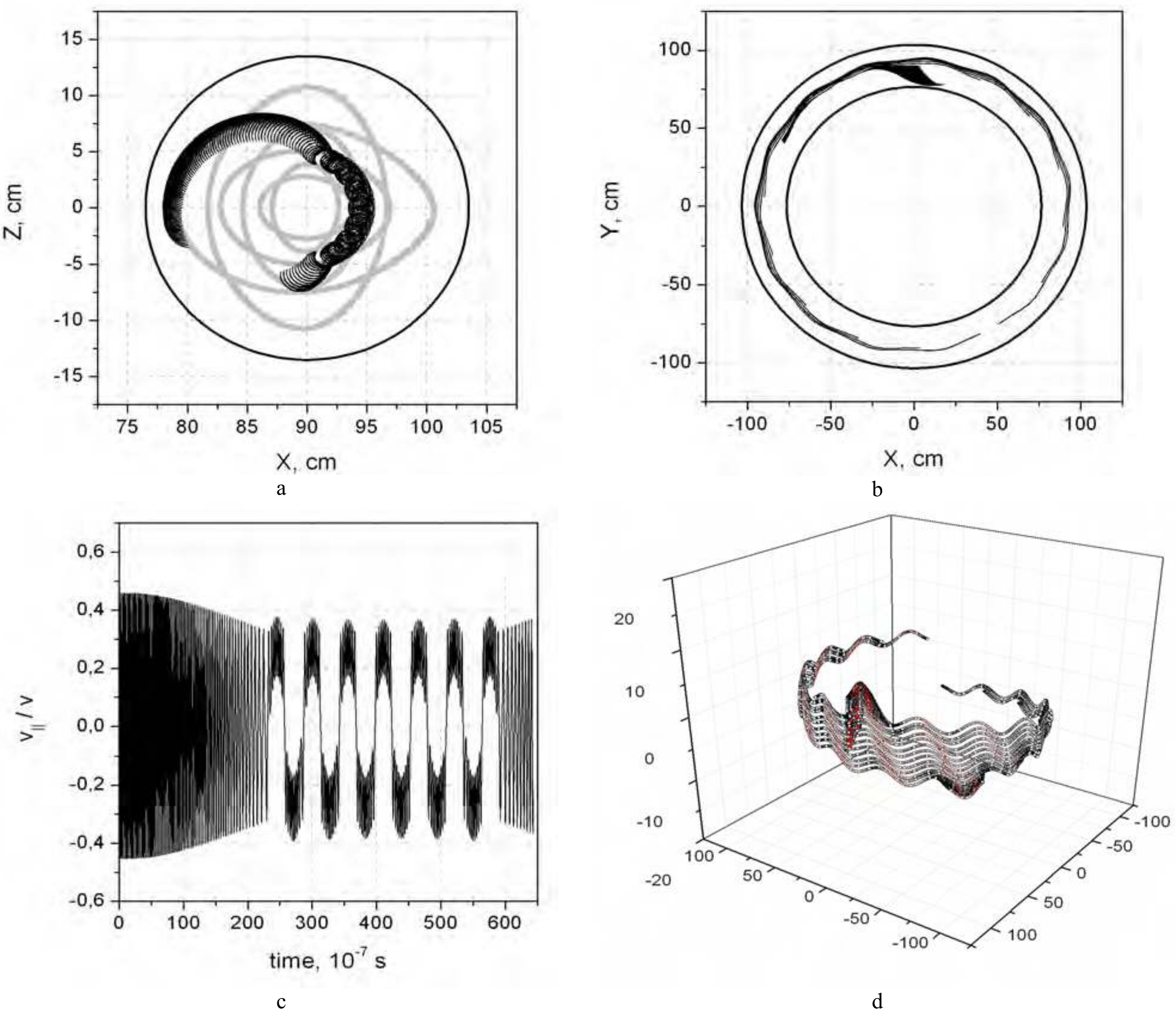


Fig.2. Particle motion *without the AC field effect and without the static perturbation*. a – trajectory projection on the vertical cross-section, b – trajectory projection on the horizontal cross-section; c – time dependence of pitch $V_{\|}/V$; d – 3D trajectory.

2) Test particle transits from helically trapped state into the toroidally trapped one and moves along a serpentine-like orbit, altering its direction for a few times at the reflection points of approx X=92 cm, Z=5 cm and X=92 cm, Z=-5 cm. These reflection points are seen on the Fig. 2b, for instance at approx. X=50 cm, Y=-75 cm or X=75 cm, Y=-50 cm. This corresponds to the time period from $t = 230 \cdot 10^{-7}$ seconds to $t = 580 \cdot 10^{-7}$ seconds on the Fig. 2c. The moment of time when $V_{\|}/V$ graph crosses zero line means that the test particle undergoes reflection at this moment and then start to move along a similar serpentine-like orbit in the opposite direction.
3) The test particle transits from the state of toroidally trapped into the state of hellicaly trapped. Since this moment ($t = 580 \cdot 10^{-7}$ on Fig. 2c) till the end of calculation it moves along a banana-like orbit similar to that in the first part. Helical field bounce period at the starting point is the following: $T_{BOUNCE} = 2\pi / \omega_{BOUNCE} = 0.8 \cdot 10^{-7}$ seconds. It is necessary to mention that the cyclotron period of electron here is $T_C = 2\pi / \omega_C = 0.125 \cdot 10^{-9}$ seconds. The time of the particle staying in the center of the confinement volume is $300 \cdot 10^{-7}$ seconds.

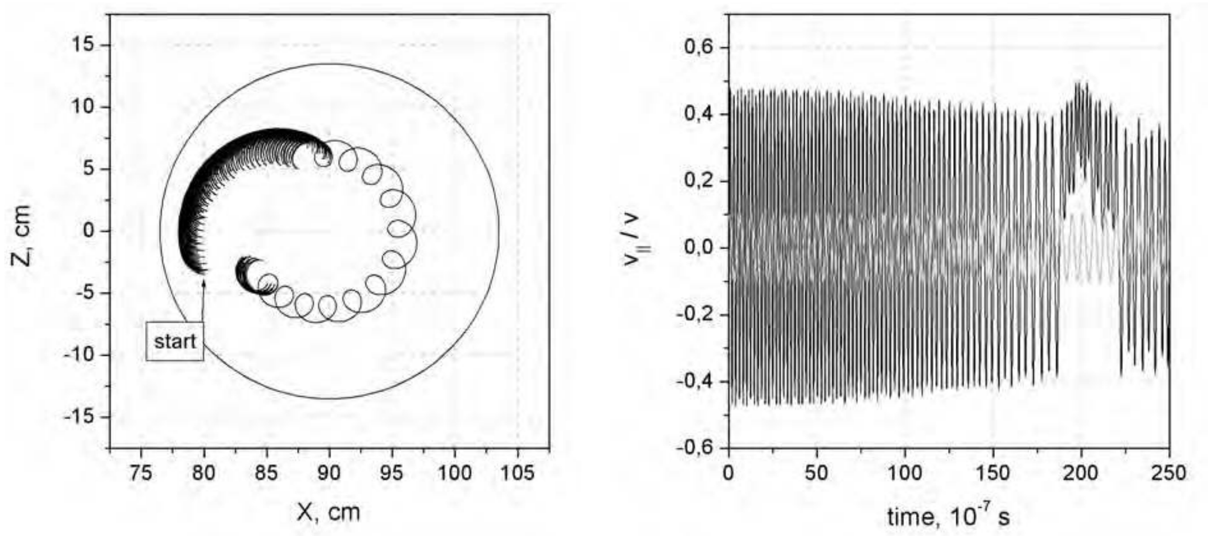


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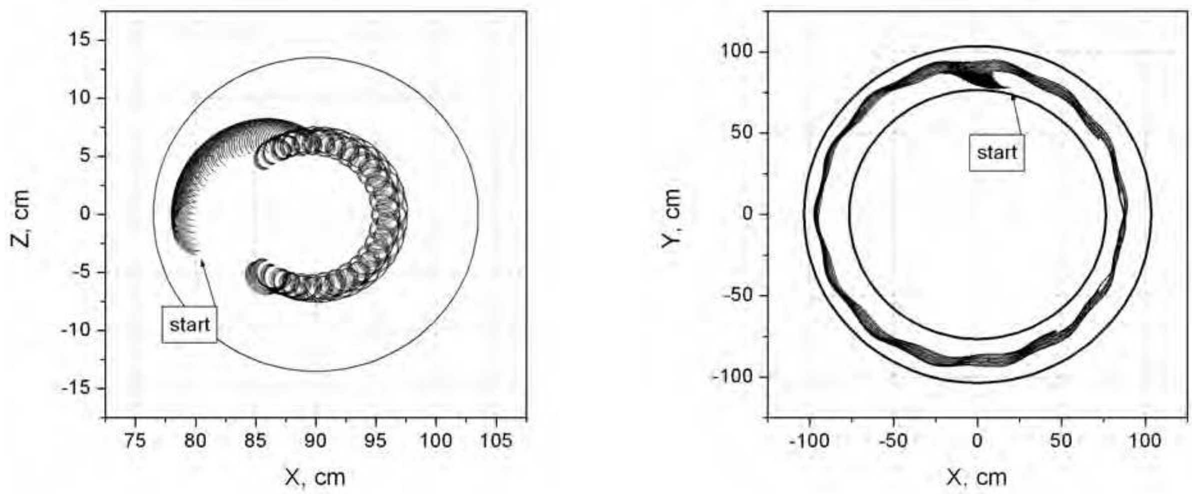
Fig.3. Particle motion *under the AC field effect of the varied in time perturbation* with $n_p / m_p = 1/1$. a – trajectory projection on the vertical cross-section; b – pitch-velocity $V_{\|} / V$ as the function of time.



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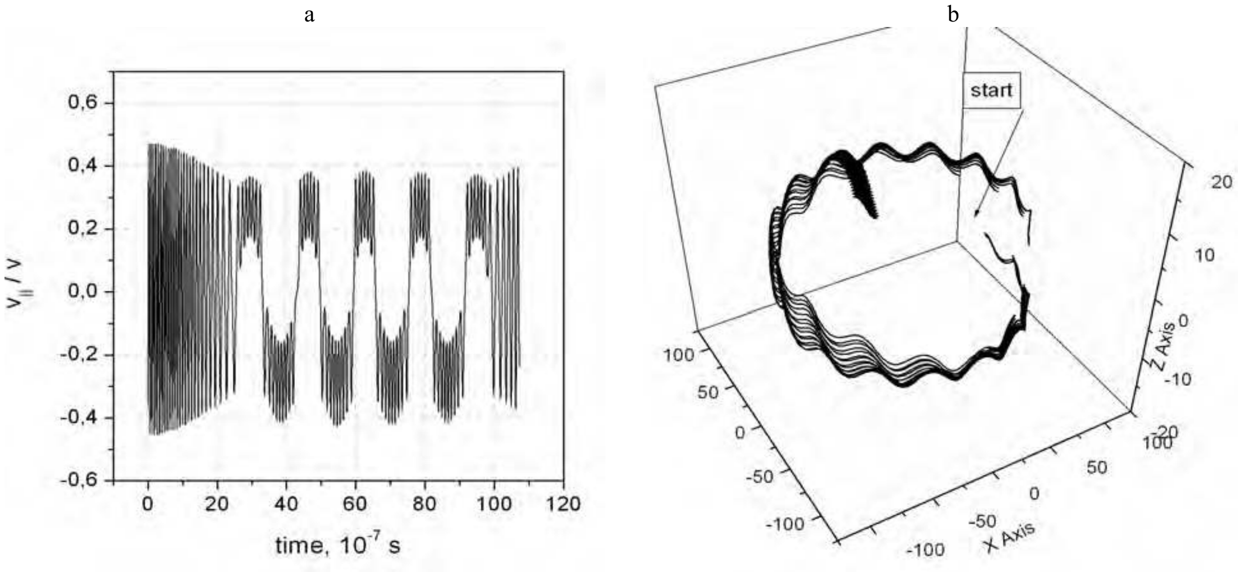

c d

Fig.4. Change of the particle motion under the AC field effect. a – trajectory projection on the vertical cross-section, b – trajectory projection on the horizontal cross-section; c – pitch-velocity $V_{\|} / V$ as the function of time; d – 3D trajectory.

Transit particle motion under the AC field effect

The perturbation can be switched on for different time intervals. However it is possible to achieve the transition of the electron from helically trapped state into the passing state only for the short time. The results of the study of such possibility we show below (Fig.3). The time of the electron staying in the core region in the state of passing particle is very short: $(220-190)\cdot 10^{-7}$ seconds. At this time the $V_{\|}/V$ graph is placed above the zero line and does not cross it, see Fig 3b, and the electron is moving along the serpentine-like orbit, see Fig 3a, from the area with X=90 cm, Z=6 cm to the area with X=86 cm, Z=-4 cm. Before the moment $t=190\cdot 10^{-7}$ seconds and after the moment $t=220\cdot 10^{-7}$ seconds electron is in the state of helically trapped particle. During these periods the test particle is moving along the banana-like orbit, see Fig 3a, from the start point to the transition point of approx. X=90 cm, Z=6 cm, and from the "reverse" transition point of approx. X=86 cm, Z=-4 cm to the point of approx X=83 cm, Z=-2.5 cm, which is the end of calculation. AC field effect on the particle entrapping / de-trapping when AC field is switched on for shorter time. Under the AC field effect in the case when the perturbation acts during the shorter time the time of the particle staying in the center of the confinement volume in the state of the toroidally trapped increases substantially (Fig.4.)

Discussion

3D trajectory (Fig. 4d) gives us the picture how the electrons can be accumulated in the magnetic trap. The electric field of a MHz frequency range should be applied to achieve the effect for electrons. Such field can be excited by a local antennae system. In the case of ions the electric field should be of kHz frequency range and two additional helical windings with independent supply can be used as a system, to excite such electric field.

ION TRANSPORT INSIDE THE TOROIDAL CHAMBER TO THE DETERMINED ANGULAR ϑ,φ COORDINATE RANGES

Choice of the ion start position

The transfer of the passing resonant particle into the helically trapped under the slowly changing in time AC field effect can be used to provide the escape of ion from the confinement volume to the definite space place outside the last closed magnetic surface.

We demonstrate such possibility on the example of boron ion ${}_{10}^{3}B$ keeping in mind the problem of "boronization" of the chamber of the toroidal magnetic traps [7]. First of all let us give some definitions. Resonant particle is the particle, that forms the rational drift surface with the twisting angle $\iota^{*}=n/m$; this surface splits into m drift islands under the effect of the magnetic field perturbation with the "wave" numbers m,n. In the case when the main magnetic field and perturbing magnetic field do not change in time, i.e. they are static, then drift islands with the fixed size (dimension) across the magnetic surfaces appear. If *the perturbing magnetic field changes in time* and *the frequency of the perturbation in its turn changes in time* then the resonant particle slowly drifts out across the magnetic surfaces and escapes from the confinement volume. This physics mechanism was proposed theoretically [8] and confirmed experimentally [9].This mechanism is considered as the technique to remove the cold alpha-particles from fusion reactors. In the case *when the main magnetic field changes in time but the perturbation does not change* it is possible to achieve that resonant particle slowly escapes the confinement volume and we see the motion of the drift island that is the $\iota^{*}=n/m$ moving drift island [10]. In this paper we show that there is a combined mechanism: the motion of the drift island in the space with the larger helical ripples and the ***transfer of the resonant passing particle into the helically trapped particle*** with its consequent escape form the confinement volume.

About the existence of the rational drift surface

Test particle is a boron ion ${}_{10}{}^{3}$B with the energy $W=3\,$keV and velocity pitch at the starting point is taken as $V_{\|}/V=-0.435$. This is so called negative passing particle. It moves in the direction opposite to the direction of the magnetic field. Spatial coordinates of the starting point are the following: $r_0=2.5$ cм, $\vartheta_0=\pi$, $\varphi_0=0$. The subject of this section is connected with the choice of starting points and particle velocity pitch $V_{\|}/V$. The problem is that to confine ions in Heliotron DR it is necessary to create the magnetic field that is not smaller than $B_0=0.6$ T. We need such parameters of the particle launching that the twisting angle of the particle should be near $\iota^{*}\approx 1$. Boron ion under the conditions mentioned above forms the rational drift surface with the twisting angle $\iota^{*}\approx 1$. The projections of the drift surface in two vertical cross-sections (at the beginning and at the half period of the magnetic helical field) are shown in grey on Fig. 5 on the background of the corresponding cross-section.

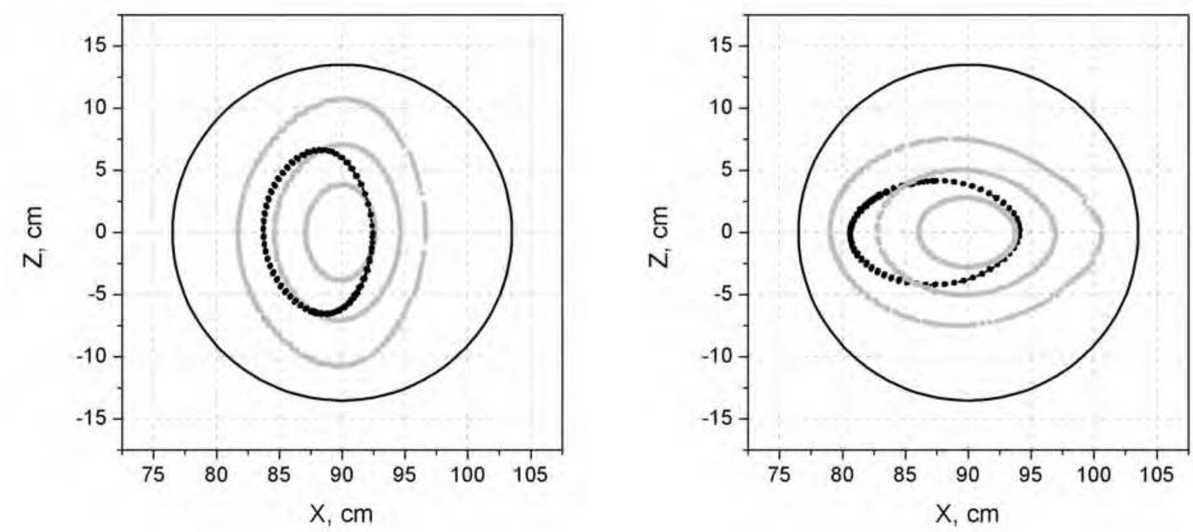

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Fig.5. Vertical cross-sections of the rational drift surface of the test particle – $_{10}^{3}B$ ion in the absence of the perturbation magnetic field. a – at the beginning of the helical magnetic field period, b – at the half-period of the helical magnetic field.

Formation of the drift island of resonant particle

If the magnetic perturbation, which is described with the scalar potential

$$\Phi_p = B_0 \frac{R_0 \varepsilon_{m,n,p}}{m_p a_h} (r/a_h)^{n_p} \sin(n_p \vartheta - m_p \varphi + \delta_{m,n,p}) \tag{5}$$

with the parameters $n_p / m_p = 1/1$, $\varepsilon_{m,n,p} = 0.00005$, $\delta_{m,n,p} = \pi/2$ acts in the magnetic configuration, then the drift island appears in the vertical cross-sections (Fig.6). The minimum time, which the formation of island takes in this case, is $\tau_{ISLAND} = 1.5 \cdot 10^{-3}$ seconds. Formation of the drift islands was studied in details in [10]. Here we explain some important issues. In order to get the full trajectory in one vertical cross-section it is necessary to gather all the footprints of the trajectory in all vertical cross-sections, i.e. under all values of the angular variable φ. In order to see the drift island at any vertical cross-section it is necessary to gather the footprints from the corresponding cross-sections. That is why the drift island changes it position if it comes from one cross-section to another.

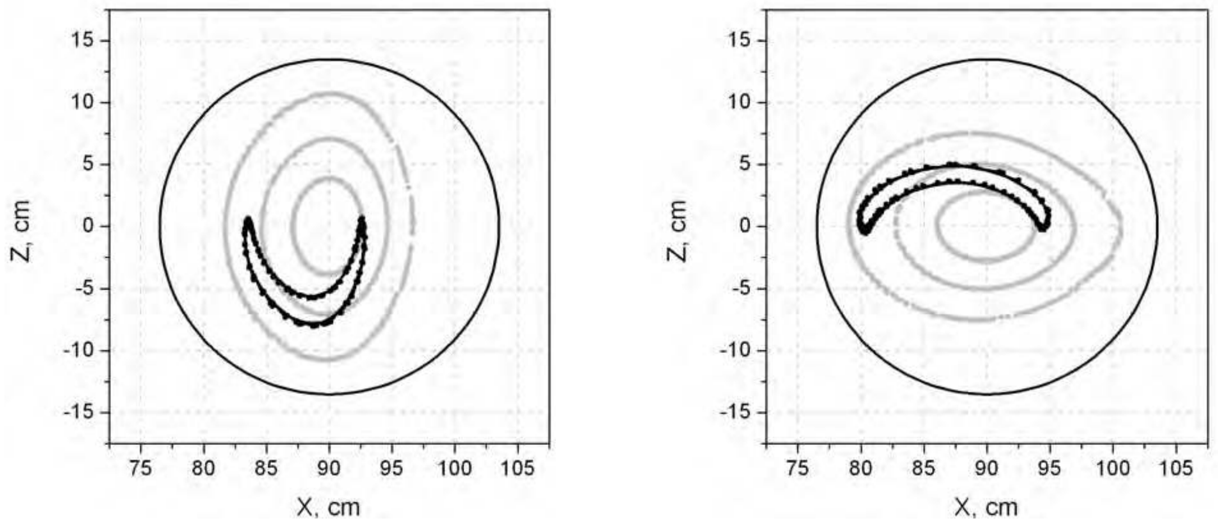

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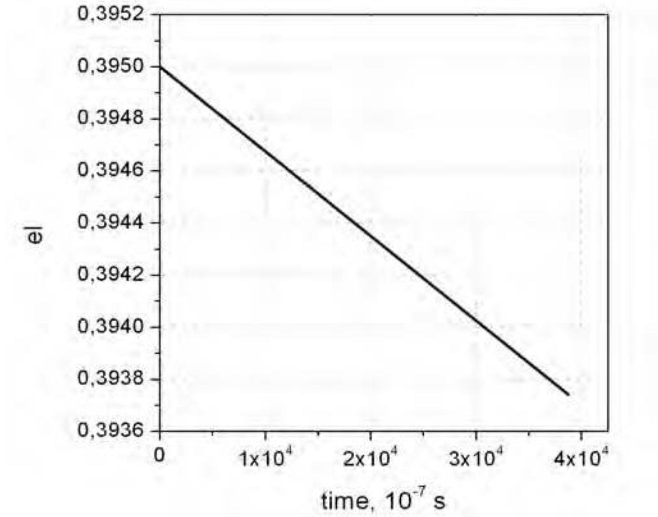
Fig.6. Vertical cross-section of the $_{10}^{3}$B ion orbit in the presence of the magnetic perturbation with the wave numbers $m_p / n_p = 1/1$ (drift island). a – at the beginning of the helical magnetic field period, b – at the half-period of the helical magnetic field.



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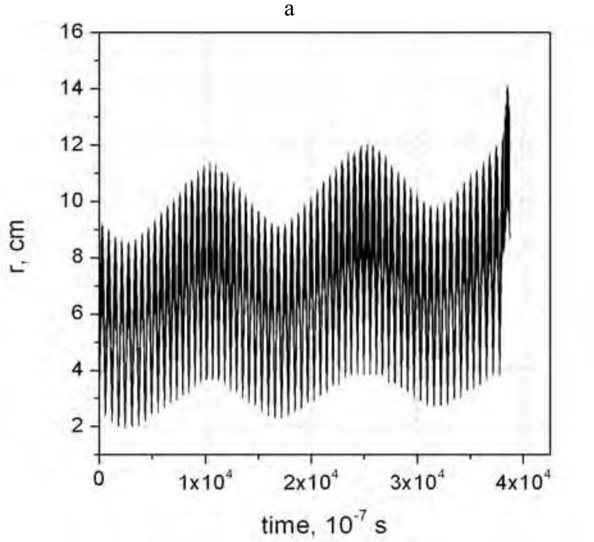

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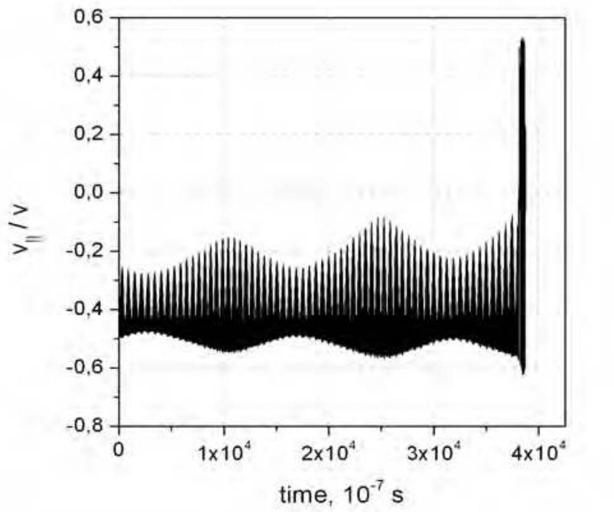

c

Fig.7. Dependence of different parameters on time. a – helical magnetic field amplitude, b – radial variable of the resonant particle, c – pitch-velocity $V_{\|}/V$.

Since this problem is very important practical one, we should like to underline that the perturbing field is produced by one of two additional coils of Heliotron DR.

Removal of the resonant passing particle from the confinement volume

If in the main magnetic field described with the scalar potential (2) the amplitude of the helical magnetic field changes slowly in time in accordance with the rule

$$\varepsilon_{n,m} = \varepsilon_{n,m,0} - \varepsilon_{n,m,1}\sin(\Omega_h t + \delta_h)\,, \qquad (6)$$

then the drift island moves across the magnetic surface.

This means that the resonant particle escapes from the confinement volume to the periphery. The results of solving the guiding center equations are shown on Fig. 7 and Fig. 8 under the parameters: $\varepsilon_{2,15,0}$ =0.395, $\varepsilon_{2,15,1}$ =0.02, $\Omega_h = 1/T_h$, where $T_h = 0.4$ seconds.

It is shown that the slow variation of the magnetic field which forms the rotational transform and twisting angle, during the time smaller than the half period of the magnetic field variation, $\varepsilon_{2,15}$ (Fig. 7a) causes the increase of the radial variable (Fig. 7b) and that fact that the pitch-velocity $V_{\|}/V$ crosses the line $V_{\|}/V$ =0, i.e. the particle becomes helically trapped. This obvious picture demonstrate the dynamics of the drift island with $n_p / m_p = 1/1$. Drift island moves outside from the confinement volume as it seen in the vertical cross-section at the beginning (Fig. 8a) and half period of the magnetic helical field (Fig. 8b).

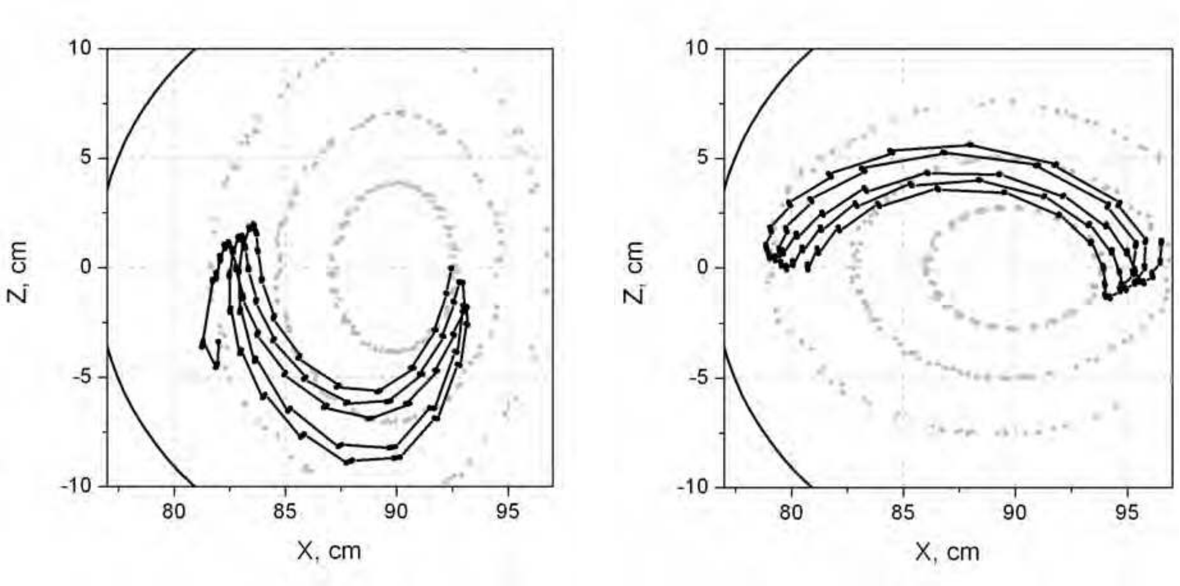

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Fig.8. The motion of the drift island in the vertical cross-section. a – at the beginning of the magnetic helical field, b – at the half period of the magnetic helical field.

The motion of the drift island takes $\tau_{ISLAND\ REMOVAL} = 3.875 \cdot 10^{-3}$ seconds. Drift island intersects the last closed magnetic surface. It is shown that the escape of the test particle is accompanied with the trapping of the particle between the bumps of the helical magnetic field.

Entrapping of the passing resonant particle between the bumps of the helical magnetic field and its escape

Resonant particle comes into the region with the increased helical filed ripples (see Fig. 9a). The toroidal coordinate takes negative values up to φ = -400. The enlarged part of the Fig 9a is presented on the Fig. 9b. The test particle entraps in this region and escapes outside of the last closed magnetic surface (Fig. 9c) just due to the trapping and radial drift in the inhomogeneous magnetic field. The enlarged part of Fig 9c is presented on the Fig 9d, where one can see that pitch alters its value from negative to positive and vice-versa. This means that the particle is trapped and alters the direction of its motion.

DISCUSSION

We would like to answer the questions, which can raise during the discussion of the effect described above.

Can we achieve the removal of the resonant particle if the magnetic perturbation field is switched off but the helical field amplitude is varied in time?

In this case passing particle is not a resonant one and it remain passing despite the helical field is varied in time.

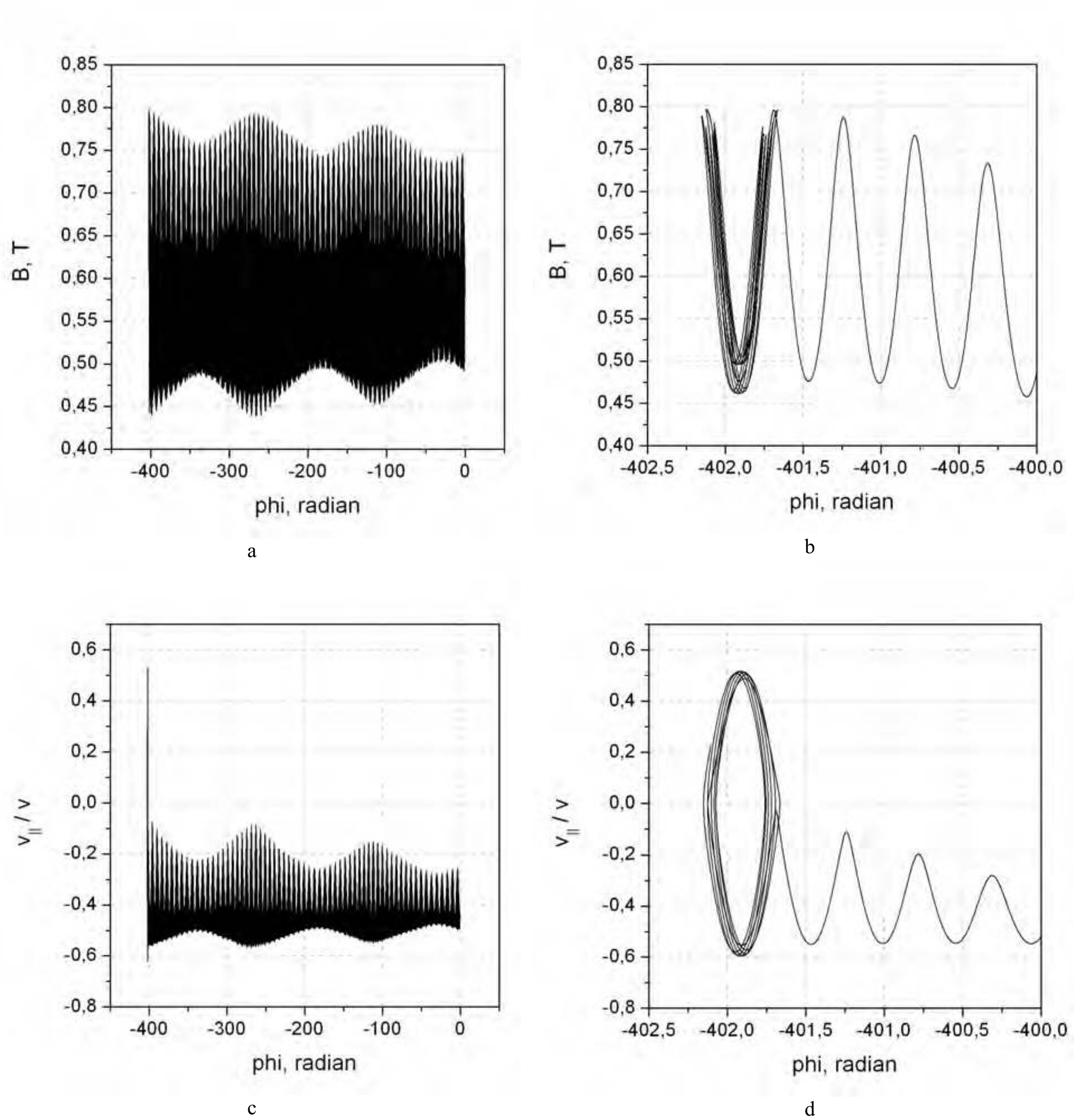

Fig.9. Dependence of different parameters on toroidal coordinate along the particle trajectory. a – magnetic field along the particle trajectory, b – enlarged part of the figure a, c – pitch of the resonant particle as a function of the angular variable φ (phi), d – enlarged part of the figure c.

How does the described mechanism depend on the $V_{\|} / V$ interval of values of the particle?

The transfer of the particle between the states "passing - resonant - helically trapped" under the AC field effect is expected in the interval of $V_{\|} / V$ values close to the natural transition. Using the slowly varied AC field it is possible to make the parameters of ion gun more corresponding the practical situation. The transfer process depends also on the relation between the phases of AC field and injecting particle parallel velocity. Statistics can be gathered with the numerical calculations of the particle motion equations to answer this question. However, it can be more informative to study this effect experimental as it was done when the presence of the transit particles was observed in Heliotron DR and their penetration into the center of confinement volume [4]. This experiment was based on the theory predictions [1,2].

To what extent the mechanism described above is limited with the use of negative passing particles, i.e. the particles with the velocity $V_{\|}$ anti parallel to **B** *?*

In the devices of small and media size with the moderate magnetic field value ($B_0 \le 5$ kG) it is possible to confine ions with velocity in the limited $V_{\|} / V$ values interval. But the principal result demonstrated here is that it is possible to create the gun of ions with the corresponding $V_{\|}/V$ value and deposit this gun inside the toroidal device in the corresponding direction relatively **B** .

CONCLUSIONS

1. Slowly varying in time AC field, which can be produced with the helical conductor current varied in time is used to affect the entrapping / de-trapping process of the particle. In the real devices the additional helical winding can produce the necessary AC field.
2. AC field $\tilde{\mathbf{E}}$ can be used for the effect on the electron entrapping/ de-trapping process to improve the penetration of injected particles in the center of the confinement volume of the heliotron type device. The expanding of the $V_{\|}/V$ value range is expected for injected electrons, which transfer from helically trapped into toroidally trapped and can penetrate into the center of confinement volume.
3. Slowly varying in time helical magnetic field can transform the resonant passing particle (forming the drift island) into the helically trapped particle and cause the escape of the helically trapped particle from the confinement volume.
4. The transfer process depends on the phase of the applied AC field. The statistics is being gathered now however the real experiment would be more informative.

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УПРАВЛЕНИЕ ПЕРЕХОДНЫМИ ПРОЦЕССАМИ ЭЛЕКТРОНОВ И ИОНОВ В ВИНТОВОМ МАГНИТНОМ ПОЛЕ С ПОМОЩЬЮ ЭФФЕКТА ПЕРЕМЕННОГО ПОЛЯ

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В этой статье показано, что переменное поле $\tilde{\mathbf{E}}$ можно использовать для инициирования процессов перехода электронов из пролетных в запертые и из запертых в пролетные с целью улучшения проникновения инжектированных частиц в центр объема удержания ловушки типа heliotron. Медленно меняющееся во времени винтовое магнитное поле переводит резонансный пролетный ион (формирующий дрейфовый остров) в состояние запертого на винтовой неоднородности и вызывает его уход из объема удержания. Медленно меняющееся во времени переменное поле, которое приводит к переходу частиц может быть создано изменяющимся во времени током в винтовом проводнике.

КЛЮЧЕВЫЕ СЛОВА: винтовое магнитное поле, процессы перехода частицы из пролетной в запертую и из запертой в пролетную, возмущение магнитного поля, переменное поле.