J. Plasma Fusion Res. SERIES, Vol. 3 (2000) 509–512

Coil System for the Resonant Pumping In/Out of Particles in Toroidal Magnetic Traps

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(Received: 18 January 2000 / Accepted: 7 April 2000)

Abstract

In order to remove impurity ions from the magnetic traps or to transport high energy ions in the center of magnetic configuration it is possible to use the drift resonance of passing particle with the rotating magnetic field perturbation with the changeable frequency. To realise these effects the coil system similar to the coils that produce local island divertor configuration can be used. The principal new proposal here is the distribution of the currents in the coil system and their variation in time.

Keywords:
drift resonance, impurity ion removal, rotating magnetic field perturbation, coil currents

1. Introduction

Impurity ions in the modern thermonuclear devices and helium ash in the future fusion reactors should be removed from the confinement volume. Impurity ions-both: high Z ions with the low energy and helium ash with the high energy - can be trapped or passing particles in the dependence on the particle velocity $V_{\|}/V$, where $V_{\|}$ is the parallel and V is the total velocity. Trapped particles can escape from the confinement volume due to radial excursion in the non axisymmetric magnetic field. Passing particles can escape from the confinement volume if their trajectories intersect the last closed magnetic surface. For other passing particles - impurity ions - it is necessary to find out the ways of removal. One of such ways is to use the drift resonance between the trajectory of the particle with the rational drift twisting angle ι^* and externally induced the rotating magnetic perturbation with the corresponding "wave" numbers (n,m) and the changeable frequency ω.

2. Drift Resonance as the Way of the Particle Removal

2.1 Resonance Condition

In the simplest case of the main axisymmetric field

$$\mathbf{B} = B_0\left\{0,(r/R)\iota(r/a),\left[1+(r/R)\cos\vartheta\right]\right\} \tag{1}$$

and the magnetic field helical perturbation

$$\delta\mathbf{B} = B_0\varepsilon_{n,m,p}(r/a)^{n-1} \left\{\sin(n\vartheta - m\varphi + \omega t), \cos(n\vartheta - m\varphi + \omega t), 0\right\}, \tag{2}$$

where r, ϑ, φ are the "quasitoroidal" coordinates connected with the circular axis of the torus with the large radius R, the small radius a and rotational transform $\iota(r/a)$, resonance condition may take the following form [1]

$$\iota^* - n/m - \omega R/mV_{\|} = 0, \tag{3}$$

The resonant trajectory of the particle takes the form of

*Corresponding author's e-mail: shishkin@vlink.kharkov.ua the helical tube which looks as the island in the meridian cross-section, so called "drift island". The radial position of the drift island can be changed if the frequency ω changes in time. Then the drift island moves in the radial direction and the resonant particle is removed.

2.2 Particle Removal

For the study of this effect in the case of the helical device the model magnetic field with the parameters and rotational transform properties of the Large Helical Device was taken [2]. The main magnetic field is modelled as $\boldsymbol{B} = \nabla\Phi$ with the following scalar potential Φ [2]:

$$\Phi = B_0 \left\{ \begin{array}{c} R_\varphi - \frac{R}{m}\sum_n \left[\varepsilon_{n,m}(r/a)^n \sin(n\vartheta - m\varphi) \right] \\ + \varepsilon_{1,0} r \sin\vartheta \end{array} \right\}. \quad (4)$$

Here index of summation $n = l, l-1, l+1$ where l is the helical field multipolarity, m is the magnetic field number. For numerical study in this paper the parameters are taken as following: $l = 2$, $m = 10$, $R =$ 390 cm, $a = 97.5$ cm, the main magnetic field on the axis $B_0 = 3$ T, the coefficients representing the harmonics of the magnetic field $\varepsilon_{2,10} = 0.705$, $\varepsilon_{3,10} = 0.032$, $\varepsilon_{1,0} = -0.056$, $\varepsilon_{2,10} = 0.007$. The main magnetic field does not change in time. However the magnetic field perturbation does depend on time. Its scalar potential takes the following form

$$\Phi_p = B_0 \frac{a}{m} \left\{ \begin{array}{c} \varepsilon_{n,m,p,0} + \varepsilon_{n,m,p,1} \sin\left[\Omega\left(\sin(\omega t + \delta_1)t \right) + \delta_2 \right] \\ \times \left(\frac{r}{a} \right)^{m_p} \sin(m_p\vartheta - n_p\varphi + \delta_3) \end{array} \right\}. \quad (5)$$

In the case considered here we take $m_p = 2$, $n_p = 1$ and $\varepsilon_{2,1,p,0} = -0.00015$, $\varepsilon_{2,1,p,1} = 0.0004$, $\delta_1 = \delta_2 = \delta_3 = \pi/2$; the frequency parameters are the following $\Omega = 1000$ rad/s and $\omega = 6000$ rad/s. From (5) one can see that the frequency of the magnetic field perturbation changes in time (Fig. 1) where $\varepsilon_{1,2,p}$ denotes the analytical expression from (5)

$$\varepsilon_{2,1,p} = \varepsilon_{2,1,p,0} + \varepsilon_{2,1,p,1} \sin\left[\Omega \sin(\omega t + \delta_1)t + \delta_2 \right]. (6)$$

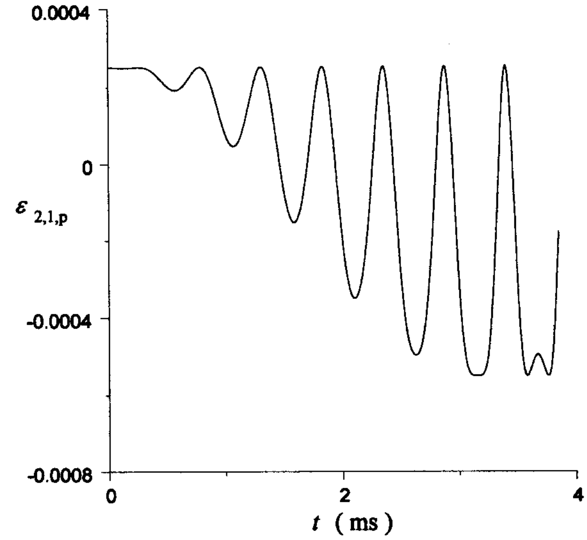

Fig. 1 The perturbing field as a function of time

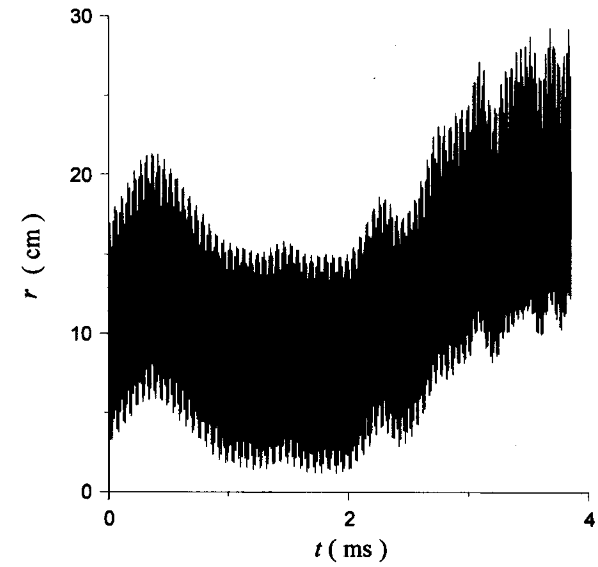

Fig. 2 Radial variable of the test particle in dependence on time.

The helium ion with the energy $W = 350$ keV and initial pitch-velocity $V_{\|}/V = 0.9$ is followed from the starting point at $r_0 = 12$ cm, $\vartheta_0 = 0.0$, $\varphi_0 = 0.0$ during 0.004 s. This particle goes away from the center of the confinement volume outside (Fig. 2).The radial variable of the test particle achieves the last closed magnetic surface. After that the particle should be taken off mechanically.

The computational drift angle of this particle $\iota^* = 0.509752$ and this value does not change drastically during the time of following.

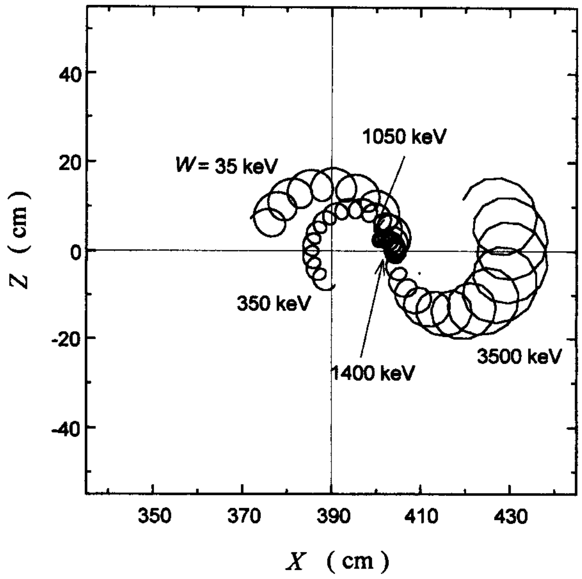

Fig. 3 Orbits of particles with different energies

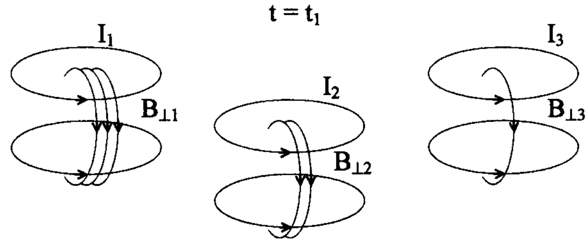

Fig. 4 Sketch of coil system at one moment of time

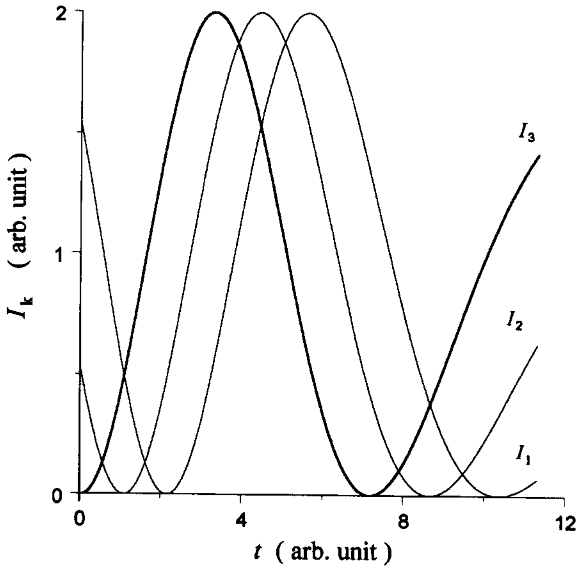

Fig. 5 Coil currents in dependence on time when the frequency does not depend on time

To understand the difference in the confinement of the particles with different energies is possible from Fig. 3, where the projections of trajectories on the meridian plane are shown at the beginning of their motion.

The particle with the energy W = 3500 keV goes away at once, its trajectory intersects the last closed magnetic surface. The particle with W = 35 keV is confined and it is not effected with the magnetic field perturbation drastically. Its computational drift angle ι^* = 0.52 , this particle does not escape. The particle with W = 1400 keV nearly "stands" at the meridian plane. The particle with W = 350 keV that is 10 times smaller than the energy of the "hot" alpha -particles is under study. It is the candidate to be named as the helium ash. This particle is removed with the perturbing magnetic field. As one can see (Fig. 3) the particles with the energy ten times smaller or ten times larger than the helium ion energy do not escape with the pumping in/out because these particles are not resonant. That is why this mechanism is selective in energy. In that sense this study confirms the results of previous investigations [1,2].

3. Coil System for the Rotating Perturbation with the Changeable Frequency

One of the ways to produce the rotating helical magnetic perturbation is to change the currents in time in the system of the helical conductors [3].

In order to produce the perturbation mentioned above it is possible to use the system of coils that consists of circular pairs (Fig. 4).

This system is similar to the coils those produce the local island divertor configuration in the Large Helical Device [4]. The number of such pairs is equal to the number of the main helical field periods m. The coils are deposited on the planes parallel to the equatorial plane. The principal new proposal here is the distribution of the currents $I_k(t)$ in the coil system, where k is the order number of the coil pair, and the dependence of currents on time. The relation between the currents shown on Fig. 5 correspond to the case of the current phase shift.

However if it is necessary to realise the perturbing magnetic field described above the current should be changed according the rule

$$I_k(t) = I_{0k}\cos\left(\Omega_l(\omega_l t + \delta_{l1})t + \delta_{l2}\right). \qquad (7)$$

If we put the ratio $\Omega_l/\omega_l = \Omega/\omega$ the distribution of

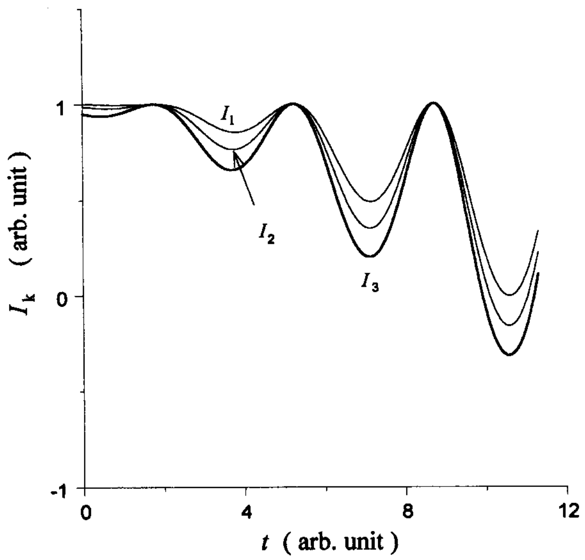

Fig. 6 Distribution of currents with the frequency changeable in time

currents takes the form as it is on Fig. 6. The amplitude of the perturbation field is order 0.0004 of the main magnetic field on the circular axis of the torus.

Interaction of the total magnetic field of the coil system $B_{\perp}(t)$ with the main helical field gives the rotating perturbation of the necessary form and leads to the effect on the resonant particles.

Further investigation will connect the calculations of particle orbits with the distribution of the currents in the coil system considered above.

4. Conclusion

In order to remove the impurity ions from the helical device it is possible to use the drift resonance of the passing particle rational drift twisting angle $\iota^* = n/m$ with the perturbing magnetic field with the "wave" numbers (m_p, n_p) and the frequency $\Omega(t)$ which changes in time.

To realise such kind of perturbations it is possible to use the system of planar coils deposited in the plane parallel to the equatorial plane of torus if the currents in each pair of coils are changed in time.

This way of pumping out of the resonant particles can be used also to solve the "reverse" task, namely, to induce the particles of the high energy in the center of confinement volume.

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