PLASMA-BEAM DISCHARGE, DISCHARGE AND PLASMACHEMISTRY

STOCHASTIC HEATING OF CHARGED PARTICLES IN ABSENCE OF FIRST ORDER RESONANCES

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Dynamics of charged particles in external electromagnetic fields in the absence of resonances proportional to the first degree of intensity of an electromagnetic field is investigated. Two schemes are investigated. In the first existence of several regular electromagnetic waves is supposed. It is supposed that frequencies and wave vector of these waves are such that the phase velocity one of beating waves is close to thermal velocity of particles. It is essential that thus organized Cherenkov resonances are proportional to square of small parameter (a square of dimensionless intensity of the field). In the second scheme is supposed that the phase of the field of wave changes by jump under the random law. Parameters of the studied systems at which one or other scheme of transmission of energy the field to particles has advantage are found.

PACS: 05.45.PQ, 52.35.MW, 41.20.JB, 41.75.Jv

INTRODUCTION

Previously, it was shown that in all cases for the same energy stored in the wave scheme with regular fields significantly more effective than scheme heating particles by the noise fields [1]. However, if resonances of particles with electromagnetic fields are absent, the only mechanisms of heating are mechanisms using the noise fields. In particular waves with random jumping phase [2, 3]. In all previous studies suggested that the resonances are usual resonances of the first-order of the field [4, 5]. It is possible to organize such resonances only in the presence medium (Cherenkov resonances), or in the presence of an external constant magnetic field (cyclotron resonances, resonances on normal and anomalous effect of Doppler). In absence of medium and the external magnetic field such resonances can't be organized. However, even in vacuum it is possible to organize Cherenkov resonances fields' proportional to the second order of the field strength.

Such resonances, in particular, are used in the FEL schemes and in schemes of the accelerating type of inverse free-electron laser. It must be said that the effectiveness of the interaction of charged particles with fields with such resonances are significantly lower than in the interaction of first-order of the field. However, as we will see below, they can also play an essential role in processes of transmission of energy from electromagnetic waves to particles. Below we will investigate mechanism of the charged particles heating in a vacuum in the absence of resonances of the first-order in the field. The essence of this mechanism is that the velocity the charged particles in the field of several waves can be in the Cherenkov resonance with the field of beating wave (combination wave).

The essence of this mechanism is that the speed of the charged particles in the field multiple waves can be in the Cerenkov resonance with the wave field heartbeat (combination wave) and, when the width of this resonance is large enough so the separatrix of this resonance touches separatrix of nonlinear resonance on other combination wave, the motion of the particles becomes locally unstable. The dynamics of particles is similar to the dynamics of particles in a random field, and there is their stochastic heating

1. STATEMENT OF PROBLEM AND THE BASIC EQUATIONS

Let's consider dynamics of the charged particles in a field of several electromagnetic waves. Expressions for electric and magnetic fields of these waves can be presented in such kind:

$$\vec{E} = \sum_n \vec{E}_n \,, \quad \vec{H} = \sum_n \vec{H}_n ,$$

$$\vec{E}_n = \mathrm{Re}(\boldsymbol{\mathcal{E}}_n e^{i\psi_n}), \quad \vec{H}_n = \frac{c}{\omega_n}[\vec{k}_n \vec{E}_n], \tag{1}$$

where $\psi_n = \vec{k}_n \vec{r} - \omega_n t$.

The equations of movement in fields (1) look like:

$$\frac{d\vec{P}}{dt} = e\vec{E} + \frac{e}{c}[\vec{v}\vec{H}]. \tag{2}$$

These equations are convenient rewrite in dimensionless variables:

$$P \equiv \frac{P}{mc}, \;\; \omega_n \equiv \frac{\omega_n}{\omega_0}, \;\; \tau \equiv \omega_0 t, \;\; \dot{\vec{P}} \equiv \frac{d\vec{P}}{d\tau}, \;\; \dot{\vec{r}} \equiv \frac{\vec{v}}{c},$$

$$\vec{E}_n \equiv \frac{e\vec{E}_n}{mc\omega_n}, \; \vec{\boldsymbol{\mathcal{E}}}_n \equiv \frac{e\vec{\boldsymbol{\mathcal{E}}}_n}{mc\omega_n}, \; \vec{k}_n \equiv \frac{\vec{k}_n c}{\omega_n}, \; \vec{r} \equiv \frac{\omega_0}{c}\vec{r} \tag{3}$$

Substituting fields (1) in the equations (2) and using dimensionless variables it is possible to receive the following, the equations:

$$\dot{\vec{P}} = \sum_n E_n \left(\omega_n - \vec{k}_n \dot{\vec{r}}\right) + \sum_n \vec{k}_n \left(\dot{\vec{r}}\vec{E}_n\right), \tag{4}$$

$$\dot{\gamma} = \frac{\vec{P}}{\gamma} \sum_n \omega_n \vec{E}_n \,,$$

where $\vec{E}_n = \mathrm{Re}\left(\vec{\boldsymbol{\mathcal{E}}}_n e^{i\psi_n}\right)$.

For the further analysis it is convenient to enter also a certain auxiliary characteristic of a particle which we further shall name partial energy of a particle which satisfies to the following equation:

$$\dot{\gamma}_n = \omega_n(\dot{\vec{r}}\vec{E}_n) . \quad (5)$$

From definition of this partial to energy follows, that it determines those value of energy which the particle would have if it moved only in the field of one n-th electromagnetic wave. Using definition of this partial energy, from the equations (4), (5) it is possible to receive the following integral of movement:

$$\vec{P} - \sum_n \mathrm{Re}(i\vec{\mathcal{E}}_n e^{i\psi_n}) - \sum_n \frac{\vec{k}_n}{\omega_n}\gamma_n = \vec{C} . \quad (6)$$

Generally the equations (4), (5) together with integral (6) can be investigated only by numerical methods. For obtain of analytical results we shall consider, that the parameter of force of each of waves working on a particle is small. In this case all description particles (its energy, a pulse, coordinate, speed) can be presented as the sum slowly and quickly varying sizes:

$$\vec{P} = \bar{\vec{P}} + \tilde{\vec{P}} \quad \gamma_n = \bar{\gamma}_n + \tilde{\gamma}_n .$$

In this case it is possible to receive the following expressions and the equations which connect fast and slow variables:

$$\bar{\vec{P}} = \sum_n \frac{\vec{k}_n}{\omega_n}\bar{\gamma}_n + C ,$$

$$\tilde{\vec{P}} = \sum_n \mathrm{Re}(i\vec{\mathcal{E}}_n e^{i\psi_n}) + \sum_n \vec{k}_n\tilde{\gamma}_n / \omega_n , \quad (7)$$

$$\dot{\tilde{\gamma}}_n = \omega_n\bar{\vec{v}}\vec{E}_n = \omega_n\bar{\vec{v}}\,\mathrm{Re}(\vec{\mathcal{E}}_n e^{i\psi_n}) ,$$

$$\dot{\bar{\gamma}}_n = \omega_n\overline{\vec{v}\vec{E}_n} , \qquad \tilde{\gamma}_n = \mathrm{Re}(\Gamma_n e^{i\psi_n}) ,$$

where $\Gamma_n = -i\omega_n\bar{\vec{v}}\vec{\mathcal{E}}_n / \dot{\psi}_n$.

The equations for fast variables can be integrated:

$$\tilde{\gamma}_n = \mathrm{Re}\left[i\omega_n\left(\bar{\vec{v}}\vec{\mathcal{E}}_n\right)e^{i\psi_n} / \omega_n - \vec{k}_n\bar{\vec{v}} \right],$$

$$\tilde{\vec{P}} = \sum_n \mathrm{Re}\left\{ ie^{i\psi_n}\left[\vec{\mathcal{E}}_n + \vec{k}_n(\bar{\vec{v}}\vec{\mathcal{E}}_n) / \omega_n \right] \right\}.$$

The equations for slow variables will get the kind:

$$\dot{\bar{\vec{P}}} = \sum_{m,n} \vec{k}_n \frac{1}{\gamma}\left[\mathrm{Re}\left(i\vec{\mathcal{E}}_m e^{i\psi_m}\right) \right]\left[\mathrm{Re}\left(\vec{\mathcal{E}}_n e^{i\psi_n}\right) \right],$$

$$\dot{\gamma} = \frac{1}{\gamma}\sum_{m,n} \mathrm{Re}(i\vec{\mathcal{E}}_m e^{i\psi_m})\omega_n \,\mathrm{Re}(\vec{\mathcal{E}}_n e^{i\psi_n}) =$$

$$= \sum_{m,n} \frac{1}{2\gamma}\omega_n\vec{\mathcal{E}}_n\vec{\mathcal{E}}_m\left[\cos\left(\psi_m + \psi_n + \pi/2\right) + \right. \quad (8)$$

$$\left. + \cos\left(\psi_m - \psi_n + \pi/2\right) \right].$$

The equations (8) are equivalent to the equation of a nonlinear pendulum (a mathematical pendulum) on which external periodic force operates. We shall show it. Let among those waves which operate on a particle, are available two waves (at number 1 and 2) which palpation form a combinational wave which phase speed, is close to average speed of a particle. We shall designate a difference of phases of these waves through θ: $\theta \equiv \psi_1 - \psi_2$. For this difference of phases it is possible to receive the following differential equation.

$$\frac{d\theta}{dt} = \vec{\chi}\vec{v} - \Omega = \Delta(\gamma) , \quad (9)$$

where $\vec{\chi} \equiv \vec{k}_1 - \vec{k}_2$, $\Omega \equiv \omega_1 - \omega_2$.

Thus we count that $\Omega / \chi \cong v$. Equation (8) we now can rewrite as:

$$\frac{d\gamma}{d\tau} = \frac{1}{\gamma}\mathcal{E}\Omega\cos\theta + F\left(\tau\right) , \quad (10)$$

where $\mathcal{E} = \vec{\mathcal{E}}_1\vec{\mathcal{E}}_2$, $F\left(\tau\right)$ – periodic function.

Let's consider that initial energy of a particle in accuracy corresponds of Cerenkov resonance of a particle with a combinational wave. It means, what: $\Delta(\gamma_0) = 0$. Besides we shall take into account that as a result of interaction of waves with particles energy of a particle has changed not on many. In this case detune it is possible to spread out in Taylor's number:

$$\Delta = \Delta(\gamma_0) + \delta\gamma\left(\frac{\partial\Delta}{\partial\gamma}\right)_{\gamma_0} .$$

Then the equations (9) and (10) will be completely closed and will accept the following kind:

$$\frac{d\theta}{d\tau} = \delta\gamma\left(\frac{\partial\Delta}{\partial\gamma}\right)_{\gamma_0} ,$$

$$\frac{d\delta\gamma}{d\tau} = \frac{\mathcal{E}\Omega}{\gamma_0}\cos\theta + F(\tau) . \quad (11)$$

The system of the equations (11) is equivalent to the equation of a mathematical pendulum taking place under influence of external periodic force $F\left(\tau\right)$

$$\ddot{\theta} = \left(\partial\Delta / \partial\gamma\right)_{\gamma_0}(\mathcal{E}\Omega / \gamma_0)\cos\theta + F\left(\tau\right) . \quad (12)$$

The equation (12) correctly describes dynamics of particles at small amplitudes of waves working on them. And the described dynamics is less than amplitude of these waves, the more precisely.

2. NUMERICAL RESEARCHES OF DYNAMICS OF PARTICLES

We are interested in the dynamics, both at small and at high field strengths. Therefore, we performed a series of numerical studies of the initial system of equations (4). We investigated the dynamics of the particle number in the most interesting field configuration, which is the field $n \geq 3$ of propagating electromagnetic waves. The dispersion diagram in Fig. 1 illustrates the appearance of combination waves.

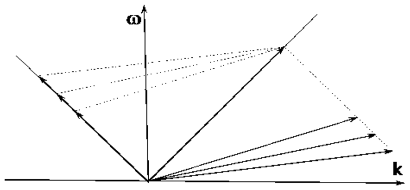


Fig. 1. The dispersion diagram of interacting waves

The conditions for the appearance of stochastic instability are conditions of overlapping nonlinear resonances of combination waves

$$(v_{ph_{i+1}} - v_{ph_i}) \leq \frac{\mathcal{E}_0}{\gamma_0^2\sqrt{k_0 v_0}}\left[\sqrt{\mathcal{E}_i\Delta\omega_{0_i}} + \sqrt{\mathcal{E}_{i+1}\Delta\omega_{0_{i+1}}} \right] , \quad (13)$$

where $v_{ph_i} = \Delta\omega_{0i} / (k_0 + k_i)$, $i = \{1, 2, ..n\}$, $\Delta\omega_{0i} \equiv 1 - \omega_i$.

We chose two values for the field strengths of each of the waves $\mathcal{E}_i = 0.03$, $\mathcal{E}_i = 0.3$ and different values of the wave numbers. The initial velocities of the particles were chosen to be zero.

Fig. 2 shows the change of energy versus time for a single particle with the initial phase $\psi_0 = 0$ three waves with strengths $\mathcal{E}_i = 0.03$, $\mathcal{E}_i = 0.3$ and wave numbers $k_1 = -0.8,\ k_2 = -1,\ k_3 = 1.2$.

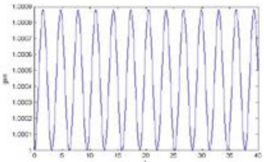


Fig. 2. The energy of single particle $\mathcal{E}_i = 0.03$

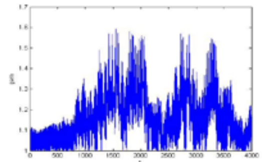


Fig. 3. The energy of single particle $\mathcal{E}_i = 0.3$

From Fig. 2 and Fig. 3 it is visible that at small strength of electromagnetic field of waves the particles oscillate regular, being in single nonlinear resonance of the combination wave. With increasing field strength under the action of fields there is transition of the particle from resonance in the resonance, dynamics of the particles motion has irregular character with significant changes of particles energy.

To determine the laws of interaction of charged particles with electromagnetic fields we will investigate the energy averaged over ensemble of 30 particles. Dependences on time of average energy with various initial values of phases $-\pi < \Delta\varphi_0 < \pi$ for three waves with strength $\mathcal{E}_i = 0.3$ and various values of wave numbers are given in plots of Figs. 4,5.

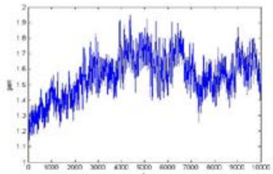


Fig. 4. Energy averaged over ensemble of particles $k_1 = -0.8,\ k_2 = -1,\ k_3 = 1.2$

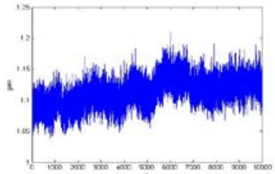


Fig. 5. Energy averaged over ensemble of particles $k_1 = -0.9,\ k_2 = -1,\ k_3 = 1.1$

Dependences on time of average energy with various initial values of phases $-\pi < \Delta\varphi_0 < \pi$ for five waves with strength $\mathcal{E}_i = 0.3$ and various values of wave numbers are given in plots of Figs. 6,7.

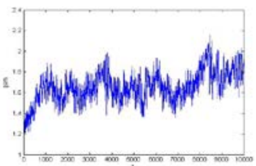


Fig.6. Energy averaged over ensemble of particles $k_1 = -0.8,\ k_2 = -1,\ k_3 = 1.2$ $k_4 = -0.6,\ k_5 = -0.4$

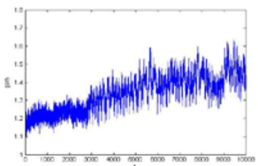


Fig.7. Energy averaged over ensemble of particles $k_1 = -0.9,\ k_2 = -1,\ k_3 = 1.1,$ $k_4 = -0.7,\ k_5 = -0.7$

As can be seen from these Figures the growth rate of the average energy of the ensemble of particles and its maximum energy depends on the magnitude of the strength of electromagnetic waves, and the number of combination waves involved in the interaction, as well as the distance between their nonlinear resonances. So the maximum energy that can collect particles in the case of overlapping of Cherenkov resonances from the combination of waves, is the sum of the distances between resonances

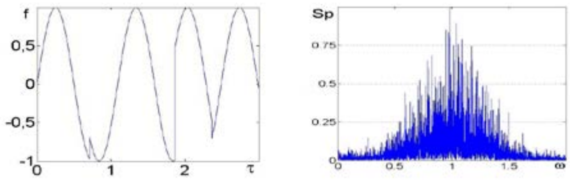
$$\sum_{n=0}^{N-1} v_{ph_{i+1}} - v_{ph_i} = v_{ph_N} - v_{ph_0}\ .$$

The degree of nonlinear resonances overlapping, depending on the amplitudes of the interacting waves, determines the time of particle transition from resonance to resonance, thereby determining the velocity and dynamics of the particles on time. The dynamics of growth of the average energy of the particles also depends on the time spent by the particles inside the nonlinear resonance.

3. MODEL OF WAVE WITH RANDOMLY JUMPING OF PHASE

For a base for formation of the wave with chaotically jumping phase, the travelling harmonic wave of kind $f(t,\vec{r}) = a\cos(\omega t - \vec{k}\vec{r} + \varphi_0)$ is taken (regular wave), to phase of which we will add stochastic function of time $\xi(t)$. For a numerical analysis the scheme of the numerical analysis which allows to vary the quantity of an interval of phases in which there is the jump of phase change, is realized. Also it is realized the possibility to select the interval of time in which, during the random moment of time, the phase jump occurs. Time of jump is supposed considerably smaller than the wave period.

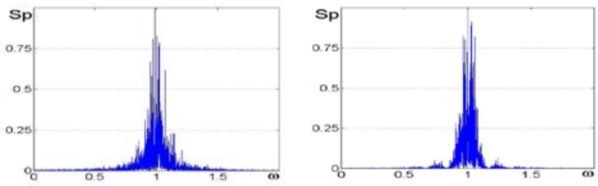
On plots Fig. 8, as example, one can see the initial part of realization (length of 1000 period) of the wave field strength time dependence at random jump of the phase at each period of wave for interval of phases jump ($-\pi < \Delta\varphi_0 < \pi$) and spectral density of power of this realization.



a *b*

Fig. 8. Field of wave and spectrum

From these plots it is visible that phase jump occurs at random moment of time at each period of the regular wave Fig. 8,a, and quantity of this jump also is random and lies in the range of phases (-π, π). The spectrum (see Fig. 8,b) is widened enough with a maximum near to unity.



a *b*

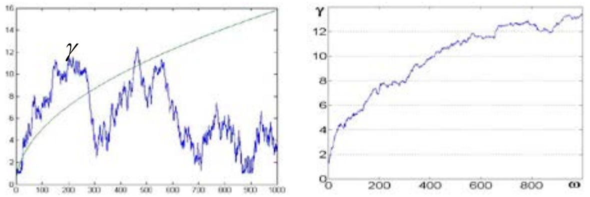
Fig. 9. Spectrum of wave: one at one period with jump ($-\pi/2 < \Delta\varphi_0 < \pi/2$) (a); one at 5-th period with jump ($-\pi < \Delta\varphi_0 < \pi$) (b)

With increasing of the interval of time on which there is jump of the phase and reduction of an interval of the phase jumps, the spectrum of the wave is considerably narrowed see plots Fig. 9. Spectral bandwidth reduction is proportional both to reduction of quantity of jump, and increasing interval of time in which this jump takes place.

4. DYNAMICS OF PARTICLES IN THE FIELD OF WAVE WITH RANDOM CHANGING PHASE

The dynamics of the particle obeys to the vector equation (14), in which $\xi(t)$ is a stochastic function changing under the law described above. Numerical modeling of the particle motion in the field of wave with chaotically changing phase is carried out in the absence of a magnetic field $H_0 = 0$ at various intervals of change of the phase jump ($-\pi < \Delta\varphi_0 < \pi$) and various intervals of time in which, at random moment, there is the phase jump.

On Fig. 10 time dependence of the energy change for single particle with initial phase $\psi_0 = 0$ and averaged on ensemble from 30 particles with initial phases from interval ($-\pi < \Delta\varphi_0 < \pi$) for case of single jump at period and interval of the phase jumps ($-\pi < \Delta\varphi_0 < \pi$), is presented. On the same plot, for comparison with the diffuse law of the energies growth with time, the curve of the time dependence of the energy change is given: $\gamma_d(\tau) = \alpha\sqrt{\tau}$ at value of coefficient $\alpha =$ 0.5. The parameter of the wave force is $\varepsilon = 1$.



a *b*

Fig. 10. Energy particle gain at the field: one particle (a); ensemble averaging (b)

From these graphs it is visible that the single particle at interaction with the wave field in a random way gaining and loses energy. However when averaged over ensemble of particles (a particle with different initial phases) a certain regularity of the particles energy growth is observed.

The graphs of dependence of the particles energy on time averaged over ensemble of 30 particles for interval of jump of phases $-\pi < \Delta\varphi_0 < \pi$ and values of the force wave parameter $\varepsilon = 0.3$ and $\varepsilon = 1$ are given in Fig. 11

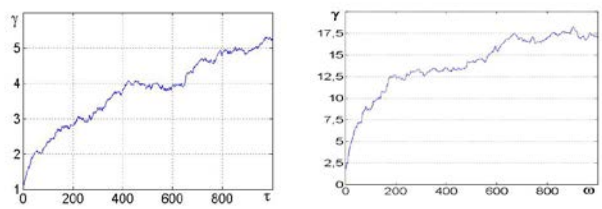


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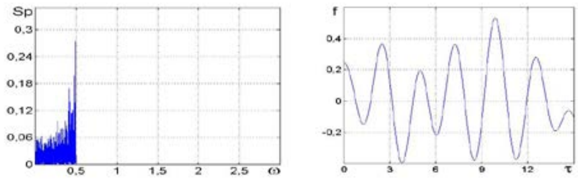
Fig. 11. Energy particle gain at the field with random jumping phase with one jump at period: $\varepsilon = 0.3$ (a); $\varepsilon = 1$ (b)

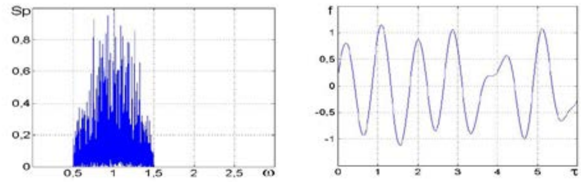
From Fig. 11 it is visible that dependence of average energy on time has close to diffusion character – smooth curves $\gamma_d(\tau) = \alpha\sqrt{\tau}$ with $\alpha = 0.5$.

For a more detailed analysis of the influence of different parts of the spectrum in the dynamics of energy exchange of charged particles with the wave field with randomly changing phase of this wave identified three main region of the spectrum: a low, basic and high frequency. In this case, the missing parts of the frequency spectrum supplemented by zero values. With the help of the inverse Fourier transform has been restored realizations which correspond to each parts of the spectrum. Figs. 12-14 shows plots the spectral power parts of spectrum and the corresponding initial part of restored field for regions low $10^{-3}\omega_0 < \omega < 0.5\omega_0$, main $0.5\omega_0 < \omega < 1.5\omega_0$ and the high frequency $\omega > 1.5\omega_0$.



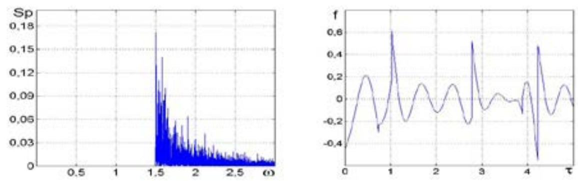
a *b*

Fig. 12. a – low region of spectrum; b – initial part of restored field from low region of spectrum



a *b*

Fig. 13. a – main region of spectrum; b – initial part of restored field from main region of spectrum



a *b*

Fig. 14. High frequency region of spectrum (a); initial part of field restored main region of spectrum (b)

For each of the reconstructed field realizations has been investigated the dynamics of particles in these fields for different values of the field amplitude. For small amplitudes of the field strength of the wave parameter's $\varepsilon \le 0.01$, the main contribution to the energy exchange between the field and particles is in the low frequency range. Figs. 15, 16 shows graphs of the longitudinal momentum (energy) of the particles from time to time, averaged over an ensemble of 30 particles using the restored realization from various parts of the spectral expansion.

Graphics averaged momentum for the high frequency part of the spectrum is similar graphs for the middle part of the spectrum. As seen from these graphs for small field amplitude ($0 < \varepsilon < 0.1$) a major role in the energy exchange of particles with field has low frequency.

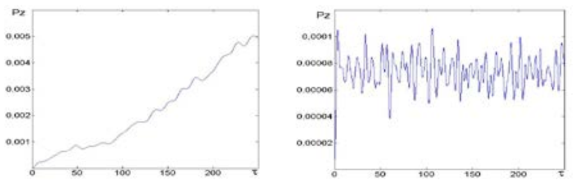


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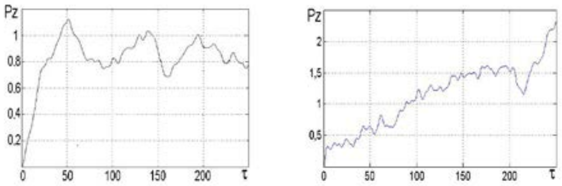
Fig. 15. The average pulse $\varepsilon = 0.01$. a – low-frequency part of spectrum;b – main part of spectrum



a *b*

Fig. 16. The average pulse $\varepsilon = 0.1$: low-frequency part of spectrum (a); main part of spectrum (b)

With increase of the amplitude ($\varepsilon > 0.1$) major role in the energy exchange of particles with field has main part of frequency spectrum.

It should be noted that the model of wave, considered above, with jumps of the phase leads to significant broadening of the spectrum and thus the most part of the spectrum can be a small effective for heating. However there are schemes with jumps of phases [6, 7] which don't lead to significant broadening of the spectrum in vicinity of basic frequency ω (by the statement of the authors). In this case efficiency of heating can be high.

5. EXPERIMENTAL INVESTIGATIONS

Higher we saw that it is necessary for formation of slow virtual waves (beating waves) that the particle interacted at least with two running towards each other waves. In the resonator filled with rare plasma such conditions can be realized at decay of a high-frequency wave on a high-frequency wave and on the plasmas wave. Such process especially effectively proceeds in conditions when distance on frequencies between the main modes of the resonator are close to plasmas frequency.

In addition, the nature of the decay process (speed of its flow, regular or chaotic dynamics) generally depends on the intensity of the decaying waves.

Besides, character of the decay process (speed of its flow, regular or chaotic dynamics) depends in general on intensity of the decaing wave. To understand these features we put a series of experiments. The resonator filled with rare plasma ($\omega_p^2 << \omega^2$) was excited in these experiments from an external source (magnetron) at a frequency 2.7 GHz. The spectrum of the oscillations excited in the resonator depending on the level of the RF power entered into resonator was studied. It was found that at the level of the input power close to 52 kW or more in the resonator regular process of decay takes place. As a result of such decay there is a low-frequency wave at frequency close to ω_p besides, there was a new high-frequency wave which frequency there was less than frequency of the magnetron on close to ω_p. Thus in these cases (cases rather small strength of RF wave) in the experiment classical regular process of decay was observed. Such processes of decay (cascade of decays) can form the required set of slow combination wave for effective self-consistent plasma heating. It should, however, bear in mind that with further increase in the amplitude of the RF wave which excites the cavity, decay process becomes less regular. Moreover at excess magnetron power over some critical value the decay process becomes irregular. Note that this occurs when the growth rate of decay instability becomes greater of the plasma frequency. The listed above features are illustrated by Figs. 17-20. In these figures the spectrum of the excited oscillations is presented at the inputting power of 52 kW (see Fig.18). Plasma frequency in these figures isn't presented. When the power of the excited oscillations increased that the spectrum of the excited oscillations has essentially extended. When reaching of power level 167 kW the spectrum becomes almost continuous (see Fig. 19). Dependence of the spectrum width on the level of input power is presented on Fig. 20.

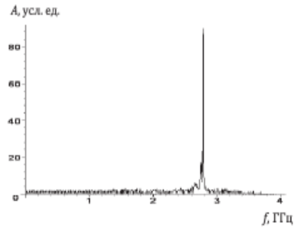


Fig. 17. Oscillations spectrum at P=17 kW

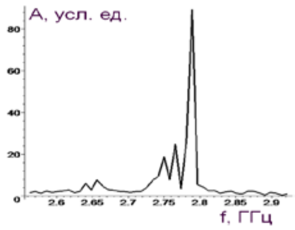


Fig. 18. Oscillations spectrum at P=52 kW

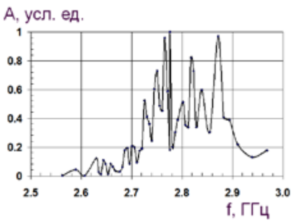


Fig. 19. Oscillations spectrum at P=167 kW

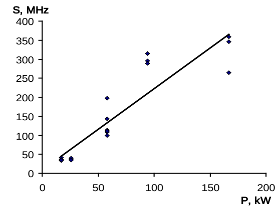


Fig. 20. Dependence of the spectrum width on the input power P

CONCLUSIONS

To compare the effectiveness of a set of energy particles in the combination of waves (in terms of overlapping nonlinear resonances of the second order in the field), and in the wave field with a randomly jumping phase will proceed from the natural assumption of the equality of power in the regular waves and wave with jumping phase $W_{reg} = W_{ch}$.

Here we have:

$$W_{reg} = \sum_{i=0}^{N} \varepsilon_i^2 \Delta\omega_i \sim \varepsilon_{reg}^2 N / Q;$$

$$\Delta\omega_i \sim 1/Q_i;\ W_{ch} = \varepsilon^2 \Delta\omega_{ch};\ \Delta\omega_{ch} \sim 1.$$

From these relations we find the following relation between the amplitudes of the regular wave and noise wave: $\varepsilon_{reg}^2 \sim \varepsilon_{ch}^2 Q / N$.

We will also use the natural assumption that at development of dynamic chaos, between the regular and the amplitudes of the noise field exist the relation:

$\varepsilon_{comb} \sim \varepsilon_{reg}^2 \sim \varepsilon_{ch}$. In this case, one can enter the following coefficient of efficiency $K = (Q \cdot \varepsilon_{ch}) / N$.

If this ratio is greater than one ($K > 1$), efficiency of the heating by the field of regular wave is higher than the heating by the noise field.

The provided experiment show that in the cavity filled with the rare plasma, it is possible to realize the conditions for heating of plasma by exciting in the cavity several eigenmodes of the resonator. Note also that the scheme described above is relevant only to the heating of the plasma at relatively low field strengths. If the power source rf oscillations (magnetron) which excites resonator close to 150 kW or more, in the cavity developing a modified decay. The fields excited thus are ramdon and there is no need for realization of the described mechanism.

This work was supported in part by special-purpose program "Perspective study of plasma physics, controlled thermonuclear fusion and plasma technologies." (Order of Presidium of the National Academy of Sciences of Ukraine № 151 of 12 March 2014).

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Article received 19.05.2015

СТОХАСТИЧЕСКИЙ НАГРЕВ ЗАРЯЖЕННЫХ ЧАСТИЦ В ОТСУТСТВИЕ РЕЗОНАНСОВ ПЕРВОГО ПОРЯДКА

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Исследуется динамика заряженных частиц во внешних электромагнитных полях в отсутствие резонансов, пропорциональных первой степени напряженности электромагнитного поля. Исследуются две схемы. В первой предполагается наличие нескольких регулярных электромагнитных волн. Предполагается, что частоты и волновые векторы этих волн таковы, что фазовая скорость волн биения близка к тепловым скоростям частиц. Существенно, что таким образом организованные черенковские резонансы пропорциональны квадрату малого параметра (квадрату безразмерной напряженности поля). Во второй схеме предполагается, что фаза поля волны изменяется скачком по случайному закону. Найдены параметры изучаемых систем, при которых имеет преимущество одна или другая схема передачи энергии поля частицам.

СТОХАСТИЧНЕ НАГРІВАННЯ ЗАРЯДЖЕНИХ ЧАСТИНОК У ВІДСУТНОСТІ РЕЗОНАНСІВ ПЕРШОГО ПОРЯДКУ

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Досліджується динаміка заряджених частинок у зовнішніх електромагнітних полях при відсутності резонансів, які пропорційні першому ступеню напруженості електромагнітного поля. Досліджуються дві схеми. У першій передбачається наявність декількох регулярних електромагнітних хвиль. Передбачається, що частоти і хвильові вектори цих хвиль такі, що фазова швидкість однієї з хвиль биття близька до теплових швидкостей частинок. Істотно, що таким чином організовані черенковські резонанси пропорційні квадрату малого параметра (квадрату безрозмірної напруженості поля). У другій схемі передбачається, що фаза поля хвилі змінюється стрибком за випадковим законом. Знайдено параметри досліджуваних систем, при яких має перевагу одна або інша схема передачі енергії поля частинкам.