IMPACT OF WAVE PHASE JUMPS ON STOCHASTIC HEATING

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Interaction of charged particles with fields of random waves brings about known effects of stochastic acceleration and heating. Jumps of wave phases can increase the intensity of these processes substantially. Numerical simulation of particle heating and acceleration by waves with regular phases, waves with jumping phase and stochastic electric field impulses is performed. Comparison of the results shows that to some extent an impact of phase jumps is similar to the action of separate field impulses. Jumps of phase not only increase the intensity of resonant particle heating but involves in this process non-resonant particles from a wide range of initial velocities.

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INTRODUCTION

As known, particles are heating up in collisions with a field of random waves. Jumps of wave phases can substantially increase the intensity of heating. Waves with jumping phases can also penetrate in overdense plasma, and initiate a new type of discharge [1, 2] which can be interesting for applications. Various regimes of particle heating by waves with jumping phases were considered earlier [2, 3]. Quasilinear theory for a field with exponentially decaying correlation function due to wave phase jumps was proposed in the early paper [4].

Here we analyze a contribution of wave phase jumps to heating intensity numerically. Decomposition of the waves with stochastically jumping phase on waves with regular phases and stochastic impulses is carried out and contribution of both components to heating process is found. Such decomposition is not exactly defined in numerical simulation as far as particle heating intensity depends on duration of field impulses; however it establishes correspondence between impulses and phase jumps.

Evolution of mean square velocity and velocity dispersion of resonant and non-resonant groups of particles is calculated from numerical simulation. The processes of particle heating by waves with regular phases as well as waves with jumping phase and stochastic electric field impulses are compared. It is shown that main contribution to particle heating gives jumps of phase which to some extent act similarly to separate impulses of electric field.

1. MODEL

We consider particles diffusion in velocity space in the external random electric field that is a superposition of 10 waves

$$\varphi(x,t) = \sum_{i=1}^{10} \varphi_i \cos\left(\omega t - k_i x + \alpha_i + \beta(t)\right), \qquad (1)$$

with a fixed frequency ω and wave numbers around a central value k_0. A total intensity of the field is distributed between partial waves as

$$\varphi_i^2 = \frac{2}{\sqrt{\pi}} \varphi_0^2 \frac{\delta k}{\Delta k} \exp -\left(\frac{k_i - k_0}{\Delta k}\right)^2 .$$

The parameters of a spectrum are dimensionless amplitude of potential $\sigma = (e/m)\,(k_0/\omega)^2\, \varphi_0 = 0.01$ and spectrum width $d = (\Delta k/k_0) = 0.04$ where e and m are charge and mass of a particle. Set of random phases α_i remains constant within each realization of a field, while a common phase $\beta(t)$ jumps in a course of particle motion. It may jump on arbitrary value with a frequency f (normalized to inverse wave period) with probability of phase jump pr.

To consider particle heating in absence of phase jumps we take $pr=0$. It is compared with two cases of waves with phase jumps which may occur once or twice during a wave period ($f = 1$, or 2) with probability $pr = 0.2$, or 0.1 respectively.

To identify the net effect of phase jumps the particle heating by separate field impulses is also considered. In numerical model we put electric field equal zero almost everywhere except for time steps in which jumps of the phase $\beta(t)$ would occur. For $f = 2$, $p = 0.1$ impulses are half as long as for $f = 1$, $pr = 0.2$ but their averaged number per unit time is the same.

2. RESULTS

Results of numerical simulation of particle acceleration and diffusion in velocity space undergoing the external random electric field (1) with jumps of phase $\beta(t)$, as well as without jumps of phase, $\beta(t) = 0$; and in a field of separate impulses, which arise at the same moments of time as jump of phases occur, are given in this section. Time is normalized to $2\pi/\omega$ and length to $2\pi/k_0$. Three types of fields are shown in Figs. 1a, 2a, 3a, and corresponding velocities of two individual particles are given in Figs. 1b, 2b, 3b. Despite the fields of waves with and without phase jumps shown in Figs. 2a and 3a look rather similar, motion of particles that were initially in resonance with waves are different. A resonant particle in waves without phase jumps all time remains in a resonance region of velocity space (see Fig. 3b) whereas it may wander at a large extension in velocity space in waves with phase jumps (see Fig. 2b).

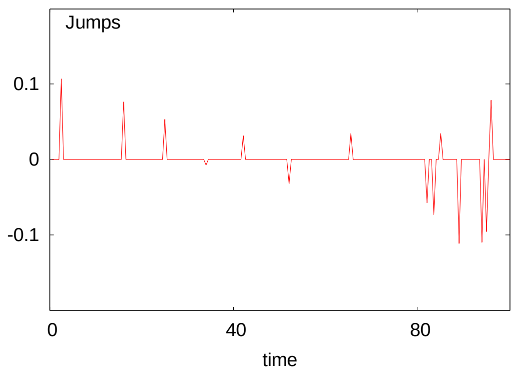

Fig. 1a. Separate impulses of electric fields that corresponds jumps of wave phase

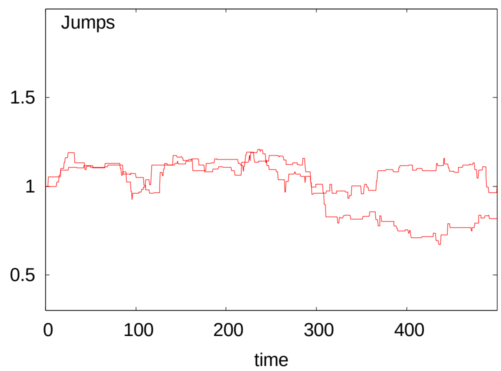

Fig. 1b. Velocity of two particles undergoing impulses of electric fields

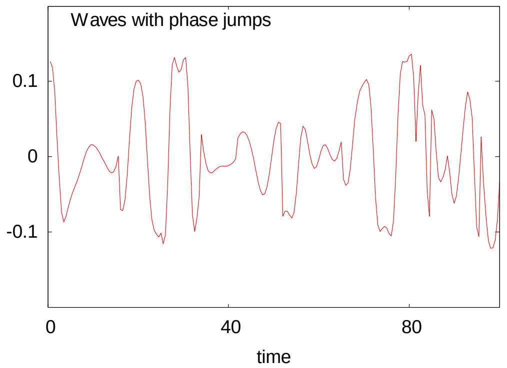

Fig. 2a. Field of 10 waves with jumps of phase

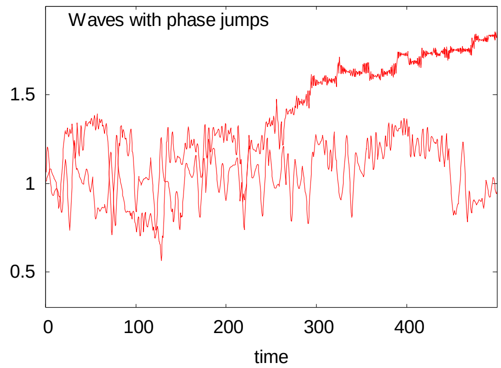

Fig. 2b. Velocity of two resonant particles in waves with jumps of phase

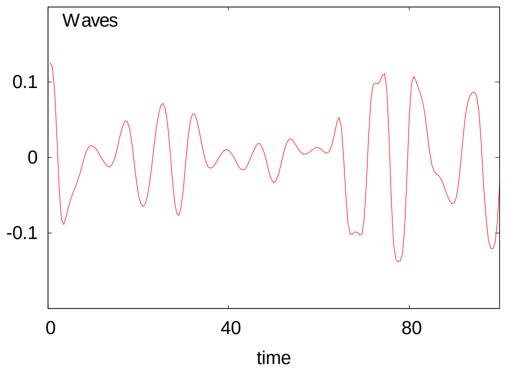

Fig. 3a. Field of 10 waves, no jump of phase

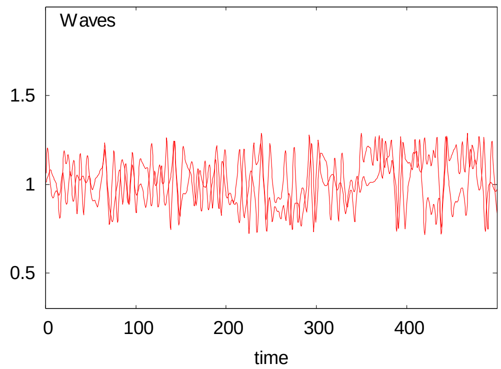

Fig. 3b. Velocity of two resonant particles in waves without jumps of phase

Thus jumps of phase introduce the effect of a noise with a wide spectrum.

In Figs. 4-7 the results of statistical averaging of particle trajectories in velocity space found in numerical simulation for various realization of field (1) are given. Evolution of particle velocity dispersion (left) and mean velocity (right) reflects the effects of stochastic heating and acceleration.

Heating of the resonant group of particles with dimensionless initial velocities $V_0 = 1$ is given in Fig. 4a. The intensity of heating is considerably higher in waves with jump of phases. The velocity dispersion still continues to grow when heating by field impulses already reaches saturation.

More interesting is a strong interaction between non-resonant particles and waves with jumps of phase (Figs. 5, 6), which are heating even faster than resonant ones (see Figs. 5a, 6a). Indeed, the impact of phase jumps on particle heating is most pronounced for non-resonant particles as far as their interaction with waves in absence of phase jumps is negligible. Along with heating, waves with jumping phase accelerate or decelerate particles (see Figs. 5b, 6b) until their velocities approach the interval of wave phase velocities.

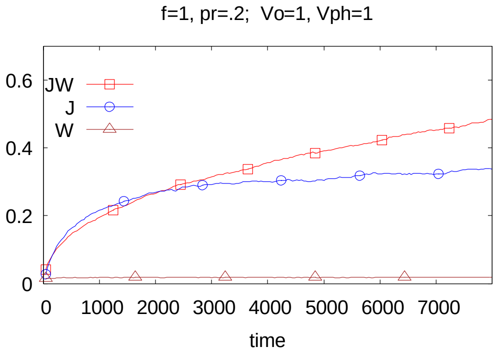

Fig. 4a. Velocity dispersion, V_0=1, V_{ph}=1.
Waves with jumps of phase – JW, field of separate impulses – J, waves without jumps of phase – W

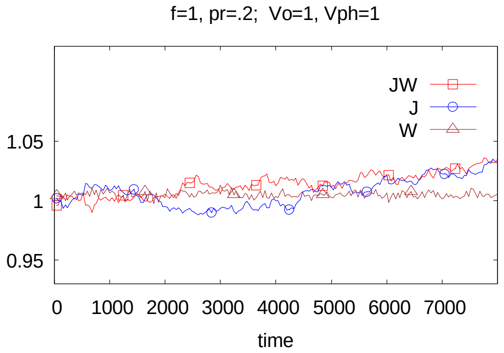

Fig. 4b. Mean velocities of resonant particles, V_0=1, V_{ph}=1

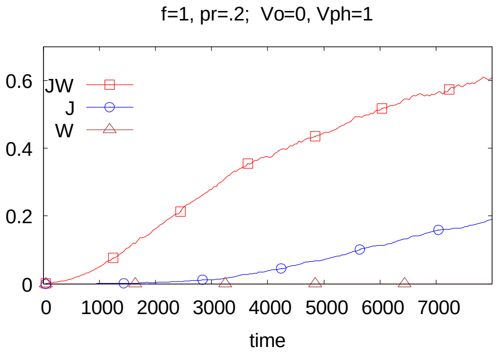

Fig. 5a. Velocity dispersion, V_0=0, V_{ph}=1

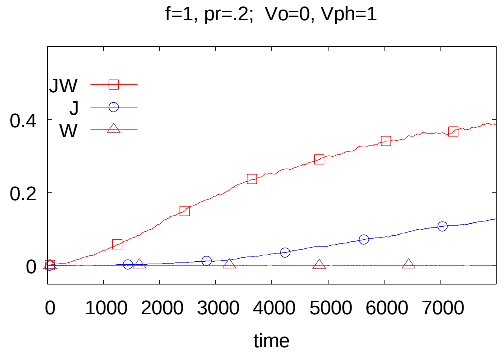

Fig. 5b. Particle acceleration in waves, V_0=0, V_{ph}=1

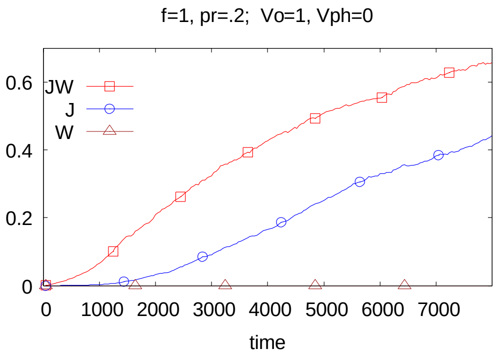

Fig. 6a. Velocity dispersion, V_0=1, V_{ph}=0

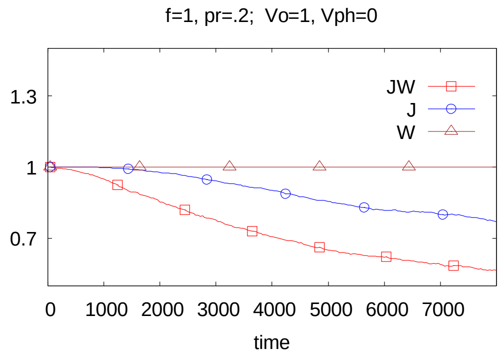

Fig. 6b. Particle deceleration in waves, V_0=1, V_{ph}=0

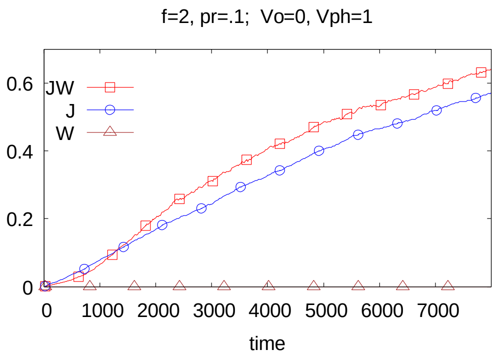

Fig. 7a. Velocity dispersion, V_0=0, V_{ph}=1, the same initial condition as in Fig. 5a, but impulses are twice shorter

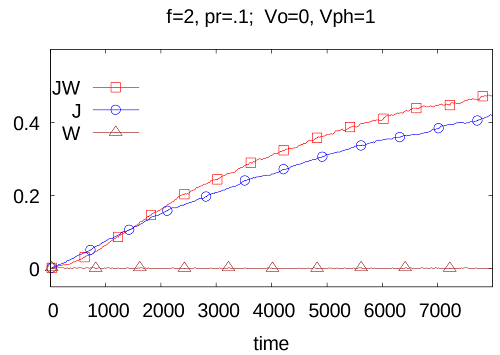

Fig. 7b. Particle acceleration in waves, V_0=0, V_{ph}=1, the same initial condition as in Fig. 5b, but impulses are twice shorter

Figs. 4-7 indicate the correspondence between particle heating by separate impulses of electric field and waves with jumping phase when impulses and phase jumps occur with equal frequencies defined by the product f × pr=0.2. Along with this heating by impulses depends also on its duration, which in simulation is proportional to 1/f. Comparison of Fig. 5 with Fig. 7 shows that shorter impulses brings out more intensive heating and acceleration of particles.

CONCLUSIONS

Numerical simulation of particle heating and acceleration by waves with regular phases, waves with jumping phase and stochastic electric field impulses was performed. Comparison of the results shows some similarity between an impact of wave phase jumps and the action of separate field impulses.

Jumps of wave phase not only significantly increase the intensity of resonant particle heating but involves in this process non-resonant particles from a wide range of initial velocities. Thus a number of particles directly heated by waves can be considerably increased.

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ВЛИЯНИЕ СКАЧКОВ ФАЗЫ ВОЛН НА СТОХАСТИЧЕСКИЙ НАГРЕВ

В.И. Засенко, А.Г. Загородний, А.Н. Черняк

Взаимодействие заряженных частиц с полями случайных волн приводит к известным эффектам стохастического ускорения и нагрева. Скачки фаз волн могут существенно увеличить интенсивность этих процессов. Выполнено численное моделирование процессов нагрева и ускорения частиц волнами с регулярными фазами, волнами со скачками фазы и случайными импульсами электрического поля. Сравнение результатов показывает, что влияние скачков фазы волн на нагрев частиц в значительной степени подобно действию отдельных импульсов поля. Скачки фазы волн не только увеличивают интенсивность нагрева резонансных частиц, но и вовлекают в этот процесс нерезонансные частицы в широком диапазоне начальных скоростей.

ВПЛИВ СТРИБКІВ ФАЗИ ХВИЛЬ НА СТОХАСТИЧНЕ НАГРІВАННЯ

В.І. Засенко, А.Г. Загородній, О.М. Черняк

Взаємодія заряджених частинок з полями випадкових хвиль спричиняє відомі ефекти стохастичного прискорення та нагрівання. Стрибки фаз хвиль можуть суттєво збільшити інтенсивність цих процесів. Виконано числове моделювання процесів нагрівання та прискорення частинок хвилями з регулярними фазами, хвилями зі стрибками фази та випадковими імпульсами електричного поля. Порівняння результатів показує, що вплив стрибків фази хвиль на нагрівання частинок значною мірою є подібним до дії окремих імпульсів поля. Стрибки фази хвиль не тільки збільшують інтенсивність нагрівання резонансних частинок, але й залучають до цього процесу нерезонансні частинки в широкому діапазоні початкових швидкостей.