STRONG FIELDS. SOME FEATURES OF DYNAMICS OF PARTICLES AND WAVES

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Some most significant results, which were got at research of wave - particle type interaction and of wave - wave type interaction are briefly reported.

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1. RESULTS CONNECTED WITH TRANSITIONS TO DYNAMIC CHAOS AT WAVE - PARTICLE TYPE INTERACTION

In our previous works (see, for example, [1-3]) the simple enough analytical conditions for occurrence of dynamic chaos for all known types of resonant interaction of a wave - particle type were formulated. The reason of occurrence of dynamic chaos was overlapping of nonlinear resonances. It seemed, what exactly this scenario of transition to chaos should cover all possible physical situations. Really, the interaction of an electromagnetic wave with the charged particle can be described by the following Hamiltonian: $H = H_0(q,p) + H_1(q,p,t)$. Here $H_0(q,p)$ - integrable part of Hamiltonian; $H_1(q,p,t) = H_1(q,p,t+T)$ - periodic perturbation. It is well known, that short-cut equations describing influence of such perturbation in singular theory of perturbation, is habitually reduced to researches of a mathematical pendulum. Therefore, it seems that the received results cover all possible processes of a wave-particle type interaction. Using these criteria, the numerous results were received, from which we shall note only one - opportunity of unlimited acceleration of the charged particles by an electromagnetic wave in vacuum at overlapping of cyclotron resonances. The importance of this result is caused by that fact, that up to it only one mechanism of unlimited acceleration of the charged particles was known - it is a mechanism of an autoresonance (Davidovsky - Kolomensky - Lebedev mechanism). It is necessary, however, to emphasize, that the rate of unlimited stochastic acceleration is lower, than at the autoresonance and the quality of the accelerated ensemble of particles is much worse. Now it was revealed by us, that for the description of nonrelativistic particles the short-cut equations are not equation of a mathematical pendulum, but system of the equations, which are topology equivalent to Duffing oscillator. Duffing oscillator, in contrast to a mathematical pendulum, has two free parameters. This facts are lead to the result that at change of amplitude of a wave, in which the particle is, its phase portrait (phase portrait of Duffing oscillator) can qualitatively changed. Presence of such qualitative change of a phase portrait is a reason of chaotic dynamics appearing. As an example of such scenario of transition to chaotic dynamics we have considered a task about movement of the charged particle in a constant magnetic field and in a field of an electromagnetic wave. It had shown that in nonrelativistic case this scenario is realized. In more details with these results it is possible to familiarize in [4].

2. RESULTS CONNECTED WITH LASER ACCELERATION

At acceleration of electron by laser radiation the accelerated particles oscillate in a laser field. At that the intensive radiations arise. This radiation, as well as the radiation in cyclic accelerators, can limit energy, which can get accelerated particles. The restrictions on the maximal energy can be received by equating accelerating forces to forces of radiating friction. So, for example, in work [5], considering acceleration of electrons by a field of laser radiation, the authors have equated force of radiating friction to accelerating forces (forces of high-frequency pressure). They have found, that in a field of laser radiation the electrons can not get energy large, than 200 MeV ($\lambda \sim 1 \mu k$). At that, as force of high-frequency pressure and force of radiating friction both are proportional to ε^2 ($\varepsilon = e \cdot E / mc\omega$ - parameter of wave force), this result does not depend from intensity of a laser field. In this sense he is universal.

In works [6,7] had shown, that the forces of friction, including forces of radiating friction, can promote transfers of energy from an external laser field to accelerated particles. Besides is shown, that the restriction on the maximal size of energy in 200 Mev, which can get particles in a field of laser radiation, generally is absent. The condition that the forces of friction will promote transfers of energy from a wave to a particle there will be an inequality: $\gamma \cdot I > 1$, where the value $I = \gamma - p_z = const$ represents integral. At large intensity of a laser field $\varepsilon >> 1$ this condition is always carried out. At performance of a inverse inequality $\gamma \cdot I < 1$ the forces of friction brake particles. The reason of such influence of friction forces at laser acceleration is that fact, that the forces of friction shift a phase between of a wave and particle at interaction. This shift can promote to acceleration. Despite of fact that the accelerated particles lose their energy on radiation, this shift lead to compensation of these losses and to additional acceleration of particles. It is necessary to note, that the losses of energy on radiation at laser acceleration are not such catastrofical as it takes place, for example, in synchrotron. Really, the particles, moving with acceleration, lose a part of the energy on radiation. And, the more energy has particle, the more energy she loss at radiation. So, if relativistic electron is moving along circular orbit, radius of which is unchanged (for example, at moving in magnetic field of cyclic acceleration). Then the expression for power of radiation one can represent as: $W = (2/3) \cdot e^2 \cdot c \cdot K^2 \cdot \gamma^4$. Here γ - relativistic factor; K - curvature of orbit.

From this formula it is visible, that the losses grow as the fourth degree of energy of a particle. This fact limits opportunities of cyclic accelerators of electrons. In the case, considered by us (laser acceleration) radius of curvature of electrons trajectory grows proportionally to square of electron energy ($K \sim 1/\gamma^2$). That is why the power of radiation does not vary with growth of energy and the problem connected with growth of radiating losses does not arise. By one of the perspective schemas of acceleration, which allow to accelerate the charged particles in vacuum is the scheme of the inverted laser on free electrons (IFEL). Such scheme of acceleration is widely discussed in the scientific literature (see, for example, [8-9]). She has many important features, from which we shall note only one - the acceleration occurs in vacuum and by cross electromagnetic waves. Earlier was shown by us [10], that in the real schemes FEL and IFEL, as a result of presence in real laser fields large number selfmodes, the stochastic instability practically always develops. Such instability essentially limits efficiency of use of these schemes. It had seemed that at use one mode laser we shall can avoid development of this instability. However, as shown in our last researches [11, 12], at increase of amplitude of accelerating laser radiation the stochastic instability develops and in this case.

3. DYNAMIC CHAOS IN LINEAR AND IN QUANTUM SYSTEMS

Now in an obvious kind is formulated paradigm that the evolutionary operator describing dynamics of system with a regime of dynamic chaos should have two unconditional properties: 1. To be stretching; 2. To be nonlinear. Certainly, these two features are necessary for realization of dynamic chaos. However, it is necessary to give some explanation concerning the second (nonlinear) property. Really, for example, it is known, that the equations of the quantum mechanics and Maxwell equations are the linear equations. However at transition from the quantum equations of movement to the classical equations of movement, and also at transition from the Maxwell equation to the equations of geometrical optics we get systems of the nonlinear equations. Such equations can describe regimes with dynamic chaos. Thus, now we are know at least two examples when in linear systems at the certain meanings of their parameters (which allow to pass to classical description) the regimes with dynamic chaos are possible. In work [13] is shown, that this situation is considerably more widespread, that the regimes with dynamic chaos is internally inherent for huge number of linear systems. In this work the results of the analysis of this feature for the quantum systems are given. On the basis of the Schrödinger equation the elementary quantum systems, in which the regimes with dynamic chaos is possible, are considered. Such system, first of all, is the three-level system. The conditions of occurrence of dynamic chaos in such system are determined. The necessary amplitudes of perturbation potential for realization of a regime with dynamic chaos are found. The characteristic times of diffuse of quantum system in space of energy are determined. The possible applications of the received results are discussed. In more details with these results it is possible to get acquainted in [14].

It is necessary to tell, that the phenomenon of quantum chaos for a long time is intensively studied (see, for example, [15]). At that, however, all authors are emphasize, that the quantum chaos is not true chaos, that in quantum chaos those quantum systems are studied, which parameters allow semiclassical description and which in a classical limit have a regimes with dynamic chaos. Many authors for this reason take the name of quantum chaos in inverted commas. In this work were studied true quantum systems. The parameters of these quantum systems were such, that they did not allow semiclassical consideration. For this reason it is possible to name a set of these phenomena as true quantum chaos.

4. DYNAMICAL CHAOS AT WAVE-WAVE TYPE INTERACTION

The second fundamental process in plasma and in plasma-beam systems is the process of wave-wave interaction. We earlier had found simple analytical conditions, at which performance dynamics of such processes became chaotic (see, for example, [16]). The proof that the process of the modified decaying always is chaotic was one of main results. The received theoretical results have allowed to give enough con-vincing interpretation to many processes proceeding at plasma-beams instability [17]. In particular, the processes of stabilization and breakdown of intense oscillation in plasma-beam systems have received an explanation. The decaying processes with stochastic dynamics can be used for controlling of spectra form of radiation that is exited by traditional highly effective generators (for example, magnetrons). However, there was left a question, under what conditions such process can be realized in experiments? What intensity of a field is necessary for this purpose? The analysis shows, for example, that the decay of cross waves on a cross wave and on Langmuir wave in unlimited plasma does not result in development of local instability [16]. In this case for development of such instability is necessary very large intensity of electromagnetic fields. The theoretical models, used in these analyses (models with weak nonlinearity) at such intensity are cease to be true. In our researches was shown, that for realization of stochastic decay the electrodynamics systems, in which the distance between own modes is enough small, can be used. Such system, in particular, can serve round metal waveguide filled by some media, which have anisotropy characteristics. Such media can play role of the element, which provides nonlinear interaction. An example of such media can be magnetoactive plasma, ferrite or ferroelectric.

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СИЛЬНЫЕ ПОЛЯ. НЕКОТОРЫЕ ОСОБЕННОСТИ ДИНАМИКИ ЧАСТИЦ И ВОЛН

В.А. Буц

Кратко изложены некоторые наиболее важные результаты, полученные при исследовании взаимодействий типа волна-частица и типа волна-волна.

СИЛЬНІ ПОЛЯ. ДЕЯКІ ОСОБЛИВОСТІ ДИНАМИКИ ЧАСТИНОК ТА ХВИЛЬ

В.О. Буц

Коротко викладені деякі найбільш важливі результаты, які були здобуті при дослідженні процесу взаємодії типу хвиля-частинка та типу хвиля-хвиля.