THE DYNAMICS OF DECAY PROCESSES IN RARE PLASMA

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The results of the experimental and theoretical investigations of chaotic decay process of HF wave on two new – HF and LF wave in the cylindrical resonator filled with rare plasma are presented. The branches of oscillations which can participate in such process are specified. The possible mechanisms of appearance of burst of radiation which follows after certain time delay after the main impulse obtained in the experiment are discussed. The qualitative agreement of the theoretical deductions with the experimental results is observed.

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1. INTRODUCTION

The decay processes of the regular waves in nonlinear mediums are studied very well. The processes of nonlinear waves interaction were also investigated in details for the cases when the waves are completely irregular and interaction occurs through intensities [1,2]. The case when the regular dynamics becomes chaotic is not enough investigated. Such processes can play an important role in plasma, especially in the beam-plasma systems [3].

The modified decay of one HF waves on new high-frequency and low-frequency can be one of the examples. In [3,4] it was obtained the criterion which can led to chaos in such system which, can be presented in the following form $VA/\omega_{lf} > 1$ where V - the matrix element of nonlinear interaction, A - the amplitude of decaying wave, ω_{lf} - the frequency of the low-frequency wave participating in the decay process. In the present report the results of the experimental and theoretical investigations of such process are given. The dispersion properties of the cylindrical wave guide partially filled with magnetoactive plasma are explored, the numerical investigations of decay process of HF wave on new HF and LF of a wave were carried out, the cascades of decays are reviewed. The process of transition to chaos in conditions of decay instability was investigated experimentally.

2. BRIEF RESULTS OF THEORETICAL INVESTIGATIONS

For realization the condition of transition to chaos it is necessary that the investigated system had enough low natural frequencies, as it is seen from stochasticity criterion expression which is given above. With reference to experiment it is necessary to specify, which waves can participate in the decay process. Moreover, it is desirable to use the system with rich dispersion when the distance between natural frequencies is small.

In the experimental setup which will be described in more detail below, the round cylindrical resonator partially filled with magnetoactive plasma is used. The frequency of a pumping wave is close to the electron cyclotron frequency. In order to define frequencies which can participate in the decay process, the simplified model was investigated.

The dispersion properties of the round cylindrical waveguide filled by cylindrical plasma are theoretically investigated. The axes of plasma and a wave guide coincide. All the system is placed into longitudinal constant homogeneous magnetic field. For the chosen model the dispersion equation describing fast symmetric waves analytically was obtained. It was analytically and numerically investigated in details near to the upper hybrid frequency. Thus it was supposed, that plasma is rare (the plasma frequency is much less then pumping wave which is in its turn close to electronic cyclotron frequency). The results of investigations of dispersion properties of the wave guide partially filled by plasma are given in Fig. 1.

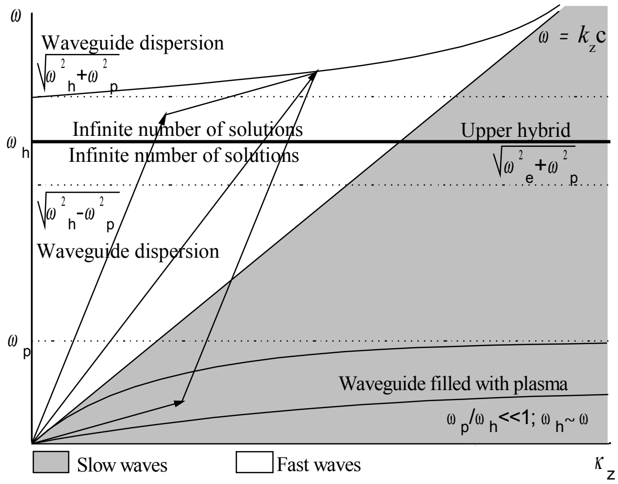

Fig.1. The dispersion of the metal wave guide filled by plasma

Is of interest the field of frequencies laying below upper hybrid frequency which is shown in Fig. 1. Here there is a large number of branches which are located almost parallelly to horizontal axis. The parallelogram in the figure corresponds to those modes which can participate in the decay.

The process of decay was investigated numerically. The model equations were obtained. The left-hand part of each of these equations corresponded to the linear oscillator, and the right part described the nonlinear interaction of such oscillators. At the performance of stochasticity criterion the dynamics of decay was irregular. It is confirmed with spectrums and correlation functions of the obtained realizations. The spectra were wide and the correlation functions quickly fell down. At disturbance of the criteria of stochasticity appearance, with decreasing of the initial amplitude of pumping wave, the spectrums became more and more narrow and time of correlation was increased.

The opportunity of realization of cascade processes was investigated analytically and numerically. In this case the wave excited during one decay HF enters another dacay process in which it represents as a pumping wave. The equations for amplitudes of the waves participating in such process are obtained, their analytical analysis and numerical examination is done. The obtained spectrums and correlation functions indicate that in such scheme the realization of chaotic regimes is possible.

3. THE EXPERIMENTAL RESULTS

The experimental setup is multimode resonator which is placed into the longitudinal magnetic field. The length of the resonator is 65 cm, radius is 7.5 cm. The value of the applied magnetic field is 950 Gs . Plasma in the resonator is created with electron bunch with energy 600 eV and the current 90 mA. The density of plasma in the resonator is $n_p : 10^9$ cm^{-3}, and its radius is $: 2$ cm. For excitation of the pumping wave in the resonator on frequency 2.77 GHz the magnetron generator is used. During carrying out of these experiments it was revealed, that the impulse of excited microwave oscillations on duration (≈ 2 μs) is much greater, than the pulse length of the magnetron. After some micro seconds after its ending the bursts of the microwave oscillations appear in the resonator. The duration of these bursts, the time of their delay concerning the main impulse, and also the number of these bursts depend on conditions of the experiment. Their recurrence has quasiperiodic character. The amplitude of each of the following burst decreases through attenuation. The characteristic form of microwaves impulses excited in the resonator, and the bursts accompanying them obtained with numeral oscillograph are presented in Fig. 2. As it seen, during the time interval between the main impulse and the burst in the resonator, the electromagnetic field does not disappear.

Occurrence of the bursts had random character on time and on amplitude. At decreasing of the value of the magnetic field on half of the length of the resonator on 25 %, the regularity of occurrence of recurring impulses of the microwave radiation increased. Recurring impulses of the microwave radiation are accompanied by occurrence of luminescence pulses of the plasma and pulses of the X-rays, caused by inhibiting of accelerated electrons from tens to several hundreds kiloelectronvolts on neutral atoms of remanent gas.

Occurrence of low-frequency oscillations in the resonator is observed experimentally. It points out that there is a nonlinear decay of the microwave oscillations excited by an external source (magnetron) on two new modes: high-frequency and low-frequency as it was discussed in the previous section. In the experiment conditions the electronic cyclotron frequency is close to frequency of excitation, and the plasma frequency is essentially less each of them. Experimental investigations have shown that with increasing of the power injected into the resonator, process of decay becomes chaotic. With its increasing the dynamics of a low-frequency mode becomes irregular. With magnification of injected power the spectrum of low-frequency oscillations becomes wide. Deductions of analytical and numerical examinations which are stated in section 2 are qualitatively well agreed with this experimental result. It allows to confirm, that in the resonator the process of stochastic decay is realized.

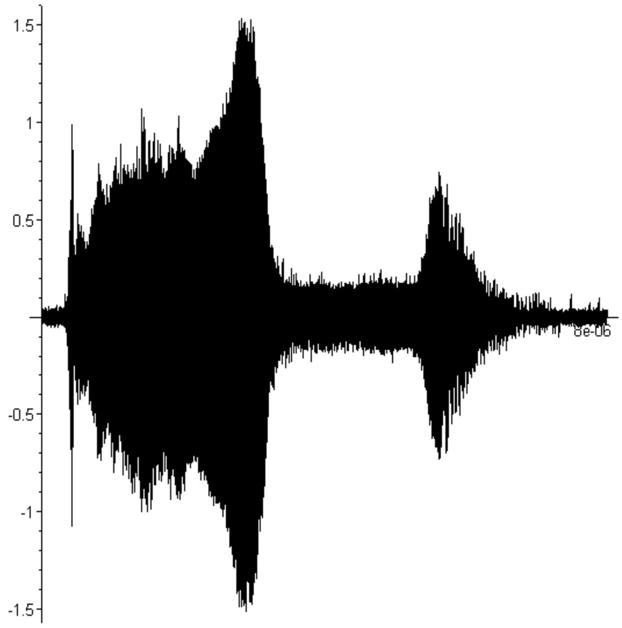

Fig.2. The oscillogram of high-frequency oscillations in the resonator

It is necessary to note, that the spectrum of oscillations which can participate in the decay, actually can be mush richer than the one which was explored in section 2. It is related the fact with that in the investigated experimental system, there are asymmetrical modes which were not took into account above.

The mechanism of occurrence of the bursts is not studied up to now. It is possible to suggest two explanations of their occurrence. On the one hand, occurrence of these impulses can be caused by electron cyclotron instability which develops after the ending of the main impulse. The other possible reason of occurrence of the bursts can be the nonlinear interaction of the waves which leads to periodic returns (Fermi-Pasta-Ulam problem).

For checking out of the first hypothesis the estimation of the increment of electronic cyclotron instability which is proportional to derivatives of distribution function of electrons of plasma on traversal and longitudinal velocities has been made. Generally the increments of cyclotron instability appeared large enough. In order to explain occurrence of the bursts as a result of development of this instability it is necessary to guess, that in the experiment formed the distribution function with the strongly pronounced plateau. Realization of such function in experiment is represented improbable.

In the second case the model of nonlinear string considering quadratic nonlinearity is used. In numerical calculations returns are observed, particularly in the case when at the initial moment of time the first space harmonic is excited in a string. The qualitative analysis of return processes shows, that it is necessary to excite several hundreds of natural modes of the resonator in order to realize return processes.

Now there are no experimental information concerning the view of distribution function of particles of plasma. There is also no information about quantity of modes which are excited in the resonator. For this reason we cannot make the unequivocal choice between these two possible mechanisms of bursts occurrence.

4. CONCLUSIONS

Experimentally was demonstrated the opportunity of realization of chaos dynamics of modified decay of one HF modes in plasmafiiled electrodynamical structure on new modes, one of which remains high-frequency, and second is low-frequency (plasma). The results of numerical and theoretical investigations qualitatively agree with experimental results. The obtained results can be used for development of broadband noise generators.

However, in experiment new circumstances was obtained – the occurrence of bursts of radiation, which explanation needs additional investigations.

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ДИНАМИКА РАСПАДНЫХ ПРОЦЕССОВ В РЕДКОЙ ПЛАЗМЕ

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Представлены результаты экспериментального и теоретического исследования процесса хаотического распада ВЧ- волны на две новые – ВЧ и НЧ в цилиндрическом резонаторе, заполненном редкой плазмой. Указаны ветви колебаний, которые могут участвовать в таком процессе. Обсуждаются возможные механизмы появления обнаруженного в эксперименте всплеска излучения, следующего с некоторой временной задержкой после основного импульса. Отмечено качественное согласие теоретических выводов с экспериментальными результатами.

ДИНАМІКА РОЗПАДНИХ ПРОЦЕСІВ В РІДКИЙ ПЛАЗМІ

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Представлен результати експериментального та теоретичного дослідження процесу хаотичного розпаду ВЧ- хвилі на дві нові – ВЧ та НЧ в циліндричному резонаторі, що заповнений рідкою плазмою. Вказані гілки коливань, які можуть брати участь в такому процесі. Обговорюються можливі механізми появи виявленого в експерименті сплеску випромінювання, що з'являється з деякою часовою затримкою після першого імпульсу. Відзначено якісний збіг теоретичних висновків з експериментальними результатами.