# INVESTIGATION OF CHAOTIC DECAY IN THE RESONATOR FILLED WITH PLASMA

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Some investigations of the results of chaotic waves decay in circular cylindrical resonator partially filled with magnetoactive plasma are presented. If external magnetic field is uniform there is a good qualitative agreement of the experimental and theoretical results. In the nonhomogeneous magnetic field after termination of external electromagnetic pulse the repeated bursts are observed in the resonator. The possible mechanisms of appearing of these additional bursts are discussed in this paper.
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## 1. INTRODUCTION

Nonlinear waves interaction in plasma filled electrodynamics systems has both scientific and applied meaning. Large number of natural oscillations with different structure in such systems creates wide possibilities for their using in the technical applications in particular for designing HF generators of different purposes.

It is necessary to note that in the present time decays are well investigated when natural oscillations that take part in this decay are fully regular or fully chaotic (see in particular [1,2]). The transition from regular to chaotic decay is weakly studied. In particular, in [3] it was shown that modified decay is always chaotic. The chaotic regime of decay may be used for designing noise generators.

Earlier theoretically it was shown that in the electrodynamics system partially filled with plasma the chaotic decay of HF wave into new HF and LF waves is possible [4,5]. Oscillation branches that may be used for decay process were defined theoretically. It was shown [6] that chaotic decay processes may play essential role for the limitation of the wave level excitation in the beam and plasma-beam generators. The considered in this work system is multiparametric and complicated for analysis. So it is interesting to consider in details more simple processes and systems.

In this work the investigation results of process of chaotic wave decay with defined initial characteristics are presented.

## 2. EXPERIMENTAL DEVICE AND MAIN RESULTS

The experimental device is multimode cylindrical resonator placed in the external longitudinal magnetic field. The resonator length is 65 cm, its radius is 7.5 cm. The plasma in the resonator is created by means of electron beam with energy 600 eV and current 80 mA. The plasma density is $n_p \sim 10^9$ cm$^{-3}$, and its radius is 2 cm. To excite pumping wave in the resonator at frequency 2.77 GHz the magnetron generator is used. Magnetron power varied from 15 to 170 kW. Magnetron pulse duration is 2 μs. The strength of external magnetic field is 950 Gs. In this conditions the electron cyclotron frequency is closed to magnetron oscillation frequency and the plasma frequency is significantly less then each of them ( $\omega_p^2 << \omega_H^2 \sim \omega^2$ ).

The theoretical investigations were carried out before experimental ones. It was shown that in waveguide partially filled with rare magnetoactive plasma there is a narrow band containing a large number of axially symmetrical oscillations [4, 5]. They may take part in the decay processes. Besides, in the resonator filled with magnetoactive plasma there are axially nonsymmetrical oscillations and also radial modes. Thus, there is a wide possibility of oscillation selection that may take part in the chaotic decay process.

The experiments were carried out both in the uniform magnetic field and in the nonuniform one. In the last case the field structure corresponds to magnetic trap.

The experimental investigations shown that when inputted power is increased both in uniform and nonuniform magnetic field the decay process becomes chaotic. The appearance of low frequency oscillations was detected experimentally. This points out that nonlinear decay of HF oscillations excited by external source (magnetron) into two new modes: HF and LF takes place in the system. The oscillograms of LF mode for three values of inputted in the resonator power 17, 58 and 167 kW are presented in Fig. 1. As it is seen when this power increases the dynamics of LF oscillations become no regular. When inputted power is increased their spectrum is spread (Fig. 2). The conclusions of the analytical and numerical investigations presented in [4, 5] well agree with this experimental result. This allows to assert that the regime of the stochastic decay is realized in the resonator. When experiments were carried out it was found that excited pulse duration is greater (5 μs) than magnetron pulse duration (2 μs).

Besides chaotic decay regime the additional electromagnetic bursts was observed when magnetic field was not uniform. They appeared some microsecond after termination of main pulse in the resonator. The duration of these bursts, their holdup time relatively the main pulse and their number depend on experiment conditions and are nonregular. The amplitude of every last burst is decreasing as a result of attenuation. The typical oscillogram is presented in Fig. 3. When nonuniformity of

the magnetic field increases up to 25% from maximum value the appearance of additional HF radiation pulses is more regular. When the repeated pulses of HF radiation appear the pulses of plasma lighting and X-ray appear too.

The modes that frequency and wave numbers satisfy synchronism conditions $\omega_2 = \omega_1 + \omega_3$, $k_2 = k_1 + k_3$ where index 2 corresponds to decaying mode, 1 to new HF mode and 3 to LF one decay may take part in the process of chaotic.

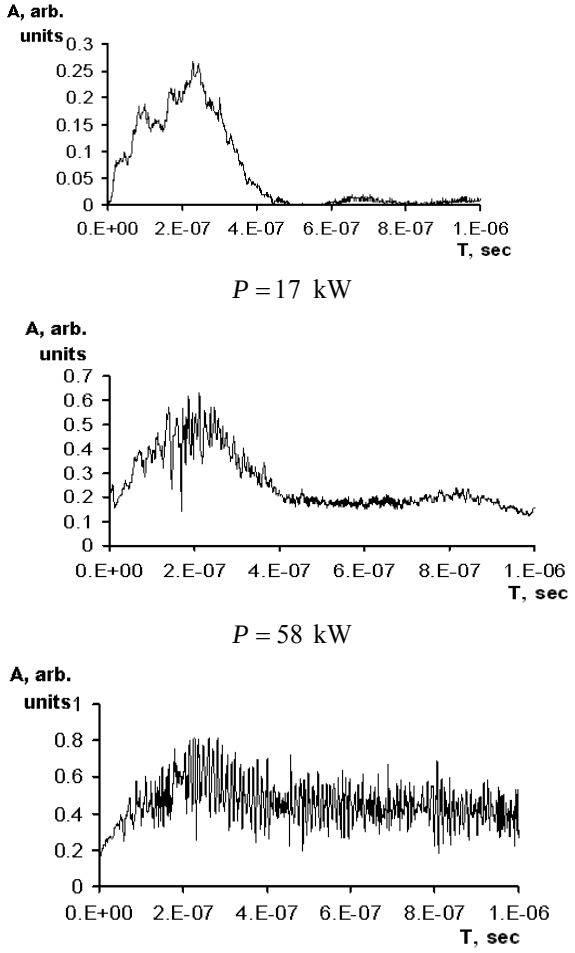


*Fig. 1. Dynamics of low frequency mode in the circular resonator filled with magnetoactive plasma depending on inputted power*

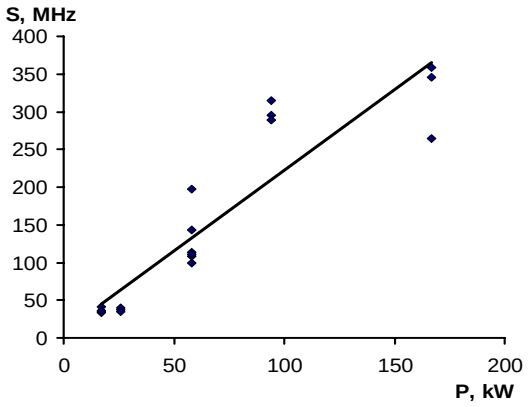


*Fig. 2. Spectrum width of low frequency mode depending on the power inputted in the resonator*

It is necessary to note that it is difficult to point out what modes take part in the decay because it is necessary to study in details the structure of electromagnetic field of the resonator partially filled with magnetoactive plasma. It is connected with large experimental difficulties.

The radiation bursts that follow after pump pulse ending are observed in the experiment. The analogous phenomenon was observed in the experiment with the device for plasma confinement with magnetic trap [7]. As it was earnestly shown by the authors of these experiments the appearance of these bursts was caused electron cyclotron instability.

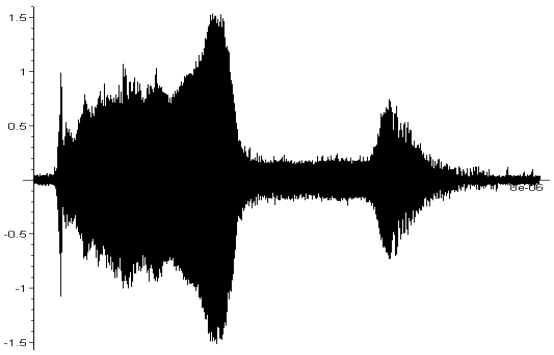

*Fig. 3. Experimentally obtained realization of excitation process of HF oscillation in the multimode resonator filled with magnetoactive plasma*

We may assume that in our experiments the bursts after the ending pump pulse are caused by electron cyclotron instability too. The estimation of increment of electron cyclotron instability was made. This increment is proportional to derivatives of distribution function relatively longitudinal and transverse velocities. At the real values of these derivatives the increment value is on many orders more than the frequency of bursts appearance.

The other possible reason of bursts appearance may be weakly nonlinear interaction of large number eigen modes excited in the resonator. In this case to describe processes in the investigated system the model of nonlinear string may be used (Fermi-Pasta-Ulam model). As it is known the recover is character in the dynamic of such system. Our estimations show (time of bursts appearance) that this mechanism may be used for explanation of bursts appearance if more than hundred modes take part in nonlinear process of resonator eigenmodes interaction.

Taking into account axially nonsymmetrical and radial modes this is the modes number that may exist in our experiments. Numerical simulation of such system have shown a possibility of periodical returns to initial conditions with character time closed to the time observed in experiment.

## 3. CONCLUSIONS

We experimentally and theoretically investigated chaotic decay of natural oscillations in the circle cylindrical resonator partially filled with magnetoactive plasma. The results of the experimental investigations qualitatively agree with the theoretical conclusions. If external magnetic field is nonuniform than in addition to the decay process the radiation bursts following after the

main pulse are also observed in the experiment. The possible reasons of appearance of these bursts are discussed.

The results of our investigations may be used for designing the generators of chaotic signals. It may be realized by means of the processes of nonlinear wave decay in the electrodynamics system filled with plasma or other nonlinear medium.

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## ИССЛЕДОВАНИЕ ПРОЦЕССА ХАОТИЧЕСКОГО РАСПАДА В РЕЗОНАТОРЕ, ЗАПОЛНЕННОМ ПЛАЗМОЙ

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Представлены некоторые результаты исследований процесса хаотического распада волн в круглом цилиндрическом резонаторе, частично заполненном магнитоактивной плазмой. Если внешнее магнитное поле однородно, имеется хорошее качественное согласие теоретических и экспериментальных результатов. В неоднородном магнитном поле, после окончания внешнего электромагнитного импульса, в резонаторе наблюдаются повторные всплески электромагнитных колебаний. Обсуждаются возможные механизмы появления этих дополнительных всплесков.

## ДОСЛІДЖЕННЯ ПРОЦЕСУ ХАОТИЧНОГО РОЗПАДУ В РЕЗОНАТОРІ, ЩО ЗАПОВНЕНИЙ ПЛАЗМОЮ

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Представлено деякі результати дослідження процесу хаотичного розпаду хвиль в круглому циліндричному резонаторі, що частково заповнений магнітоактивною плазмою. Якщо зовнішнє магнітне поле є однорідним, існує якісне узгодження теоретичних та експериментальних результатів. В неоднорідному магнітному полі, після закінчення зовнішнього електромагнітного імпульсу, в резонаторі спостерігаються повторні імпульси електромагнітних коливань. Обговорюються можливі механізми появи цих додаткових імпульсів.