Experimental investigation of relaxation of a diffused electron beam in a plasma in the presence of coherent perturbation

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We show experimentally that in the case of relaxation of a velocity-diffused electron beam a weak seeding coherent wave leads to formation of a wave packet with a width $\Delta\omega \sim \Omega_{tr}$ that upsets the quasilinear relaxation process. The observed strengthening of initial correlations is in agreement with predictions of the theory of moderately turbulent relaxation.

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Study of the relaxation of velocity-diffused particle beams is of considerable interest in itself and, in view of the comparatively simple experimental feasibility, it provides appropriate means for the verification of existing ideas concerning the nature of collisionless relaxation of a plasma. Among the numerous theoretical works and numerical experiments[1–4,6–10] that deal with the study of this process under different conditions, only a few works are experimental. Relaxation of a diffused beam was studied experimentally[5] and by means of numerical modeling[6–9] to verify the quasilinear theory[1)] in the absence of controlling initial correlations. We reconstructed the initial conditions—similar to the experimental conditions[5]—and superposed a weak coherent initial perturbation. This enabled us to verify the correctness of the quasilinear theory in the presence of weak initial correlations, and also the results of theoretical investigations and numerical experiments[4,9,10] that identify intensifications of the initial correlations in the background of natural fluctuations.

Experiments were carried out in a continuous plasma with density $n = 10^8$–10^9 cm^{-3} and electron temperature $T = 1$—3 eV which was placed in a strong magnetic field $H = 1.5$ kOe; the length of the uniform section of the plasma column was 130 cm.

The electron beam, diffused with respect to longitudinal velocities, was formed as in[5] by means of a diode gun (cathode diameter 0.8 cm) placed in a magnetic soft-iron mesh. The distribution function was measured by means of a multi-screen electrostatic analyzer placed at the terminal end of the system. Coherent signals associated with the frequency fluctuation spectrum of the system were excited at the point of beam injection into the plasma. The plasma parameters and oscillations were registered by a system of movable probes.

The dispersion curve (Fig. 1a)—determined from the measurement of wavelength as a function of frequency—shows that the first radial harmonics of the space charge wave of a magnetized plasma are excited in the experiment.

Figure 1b shows the beam distribution function at the end of the setup. The initial distribution function is sufficiently velocity-diffused and, at the end of the setup a

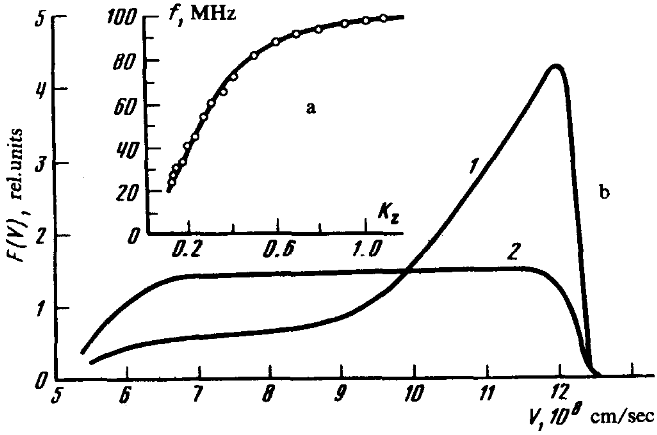

FIG. 1. a—Dispersion curve; b—beam distribution function: 1—beginning, 2—end. Beam current 1.8 mA, beam energy 420 eV.

characteristic plateau is established, regardless of the presence of an initial coherent signal; moreover, no noticeable tail is observed for the accelerated particles. Clearly, the evolution of the distribution function conforms with the quasilinear theory; this is not to say that it contradicts other theories since the plateau occurs even in the presence of a stationary monochromatic wave and constitutes, more likely, a necessary condition of equilibrium between the waves and resonant particles rather than a sufficient condition of applicability of the quasi-linear theory.

The evolution of the integral wave intensity W with respect to system length (Fig. 2) depends substantially on the presence of an initial signal. Although in both this and other cases W undergoes satuaration approximately at the same asymptotic level, nevertheless the rate of growth that characterizes an average increment, is greater in the presence of the coherent signal A. If at $A = 0$ the increment is equal to the quasilinear γ_{QL}, at $A \neq 0$ the increment (hereafter referred to as moderately-turbulent) is approximately 1.5-fold greater than the quasi-linear: $\gamma_{tb} = 1.5\ \gamma_{QL}$. Increased relaxation rate was demonstrated theoretically and in numercial experiments[4,9,10] in the presence of noticeable correlations that lead to the ordering of convective flow of phase currents. In accordance with theory, the following relationship exists between

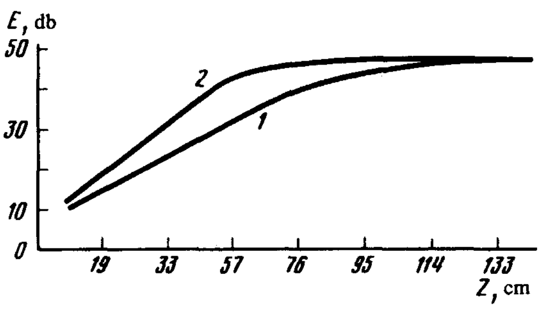

FIG. 2. Dependence of integral noise intensity on distance; 1—in the absence of initial coherent signal; 2—initial amplitude of coherent signal at frequency $f = 72$ MHz is 5-fold greater than the noise level at the same frequency. The final signal amplitude is greater than the initial by 35 db.

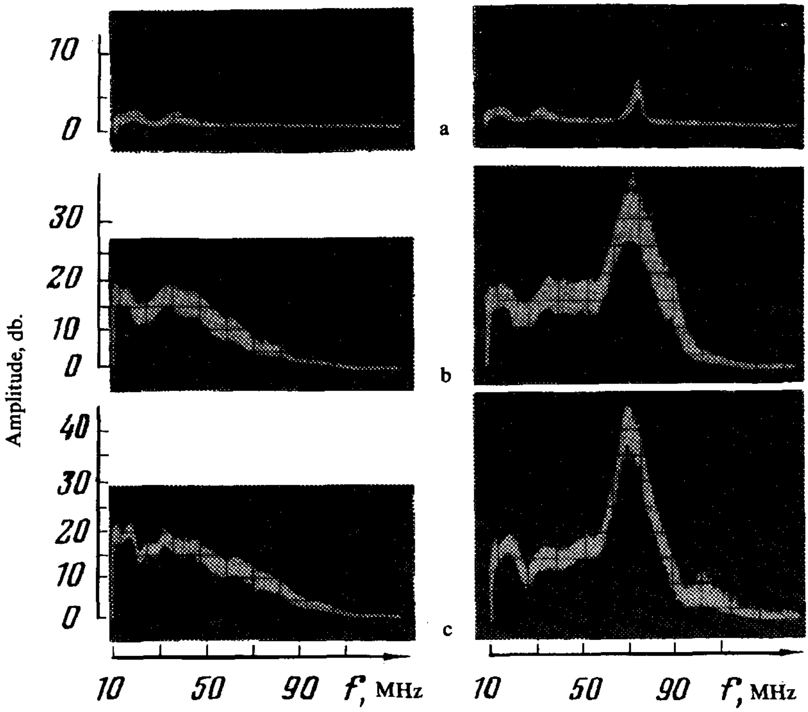

FIG. 3. Evolution of noise spectrum with respect to distance z in the absence (left column) and presence (right column) of a coherent signal at $f = 72$ MHz; a—$z = 19$ cm, b—$z = 76$ cm, c—$z = 123$ cm.

γ_{QL} and γ_{tb}: $\gamma_{tb} \approx [w/(1-w)]\, \gamma_{QL}$, where $1/2 < w < 1$ is an order parameter of phase flows. In our case, $w \approx 0.6$.

The most substantial differences of the relaxation process are observed in the evolution of the oscillation spectrum. Figure 3 shows spectra of beam-amplified oscillations which were photographed off the spectral analyzer screen in the absence of an initial coherent signal (left column) and in its presence (right column). The coherent signal modifies the spectral density considerably. The narrow line at the modulation frequency is quite apparent only at the front end of the setup (Fig. 3a). With growth, this line broadens considerably (Fig. 3b, c) such that a wave packet is formed in the spectrum around the modulation frequency whose width, according to preliminary estimates, is of the order $\Omega_{tr} = k\,(2e\phi_k/m)^{1/2}$—the frequency of oscillations of particles trapped in a wave with the amplitude ϕ_k.

In the absence of a coherent signal the measured increments of amplifying waves (Fig. 4a) are not negative and they asymptotically converge to zero in accordance with the quasi-linear theory.

In the presence of coherent perturbation, increments of the individual packet harmonics (Fig. 4b) noticeably exceed quasi-linear values at first, however, subsequently becoming negative. A mutual intensification of harmonic growth—character-

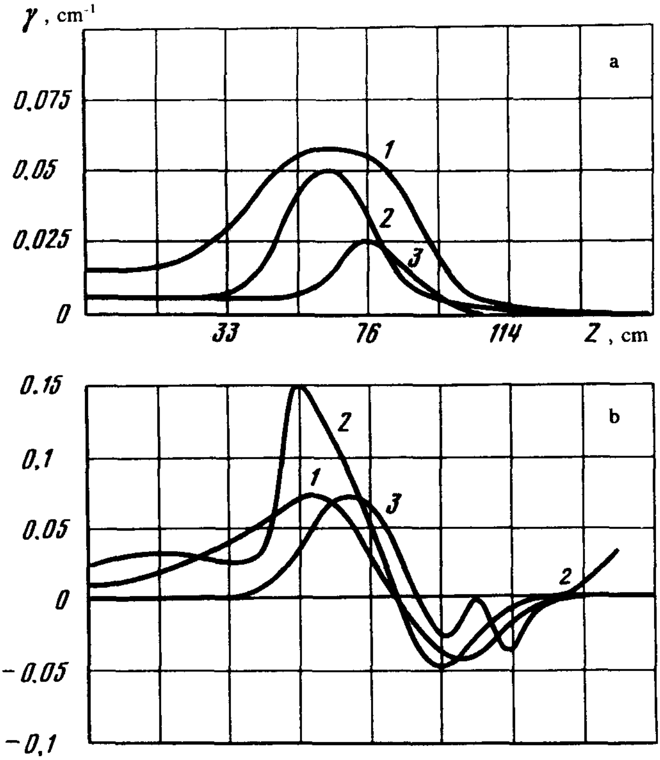

FIG. 4. Dependence of spatial increment on distance for waves with frequencies: 1—$f=40$ MHz, 2—$f=72$ MHz, 3—$f=95$ MHz. a—in the absence of initial coherent signal, b—coherent signal same as in Fig. 2.

istic for the moderately-turbulent stage—takes place and the oscillatory nature of relaxation is manifested (see Refs. 4,9,10).

The results of investigations permit the following conclusions:

1. The presence of a weak perturbation leads to the formation of a coherent wave packet with a width of the order of Ω_{tr}. Regardless of the fact that $A=0$ the relaxation process is quasi-linear, at $A\neq 0$ interaction between waves takes place leading to the mutual intensification of harmonic growth and acceleration of the relaxation process.

2. The identified enhancement of initial correlations shows that the presence of the latter causes an early-stage blow-up of the quasi-linear process which is succeeded by the moderately-turbulent process.

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[1)]For the discussion and comparison of results of these works see Ref. 9.

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