INFLUENCE OF LONGITUDINAL DENSITY GRADIENT ON THE TRANSFORMATION AND EMISSION OF TRANSVERSE WAVES FROM A BEAM-PLASMA DISCHARGE

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Investigations of the transformation of longitudinal oscillations into transverse ones in beam-plasma discharges have just barely begun [1]. We report here a theoretical and experimental investigation of the efficiency of the processes of transformation of longitudinal waves into transverse ones [2, 3] as a function of the direction of the longitudinal density gradient, and it is shown that the sign of the density gradient influences strongly the radiation intensity of the transverse waves.

Experiments on the interaction of an electron beam with an inhomogeneous plasma were performed for the purpose of studying the generation of oscillations for different directions of the density gradient. A block diagram of the setup is shown in Fig. 1 and was described, except for the plasma chamber, in [4]. The plasma chamber (the interaction region) was a glass tube 50 cm long with inside diameter 2.6 cm, placed in a homogeneous longitudinal magnetic field with intensity up to 2 kOe. The working gas was argon. The gas could be admitted at either end of the plasma chamber, making it possible to obtain pressure drops from $(4 - 5) \times 10^{-3}$ to $(8 - 10) \times 10^{-5}$ Torr across the interaction region. The plasma was produced by an electron beam of 5 A current, 10 - 12 keV energy, 110 μsec pulse duration, and 1.2 cm diameter. The plasma density was measured by a resonator method and amounted to $10^{10} - 10^{11}$ cm^{-3} at the ends of the investigated interaction region. Its concentration could either increase or decrease monotonically in the direction of the beam injection, depending on the end from which the working gas was admitted.

The plasma oscillations were received by external probes longitudinally placed outside the plasma chamber and oriented along the electric-field components E_r and E_z. They were then fed to a resonant wavemeter, an integrator, and an EPP-09 electronic potentiometer. A set of resonant wavemeters covering the 150 - 7500 MHz band was used.

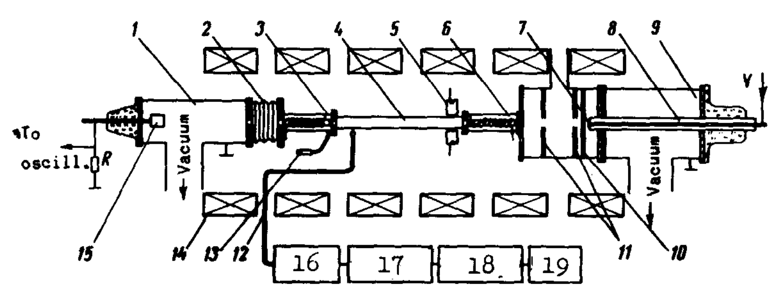

Fig. 1. Block diagram of setup: 1 - experimental chamber, 2 - bellows, 3, 6 - helical junctions, 4 - plasma chamber, 5 - resonator for measuring the plasma density, 7 - electron-gun cathode, 8 - electron gun, 9 - electron-gun chamber, 10 - anode, 11 - system of diaphragms, 12 - external probe recording the field component E_r, 13 - leak valve, 14 - magnetic-field coils, 15 - Faraday cylinder, 16 - attenuator, 17 - resonant wavemeter, 18 - integrator, 19 - automatic potentiometer.

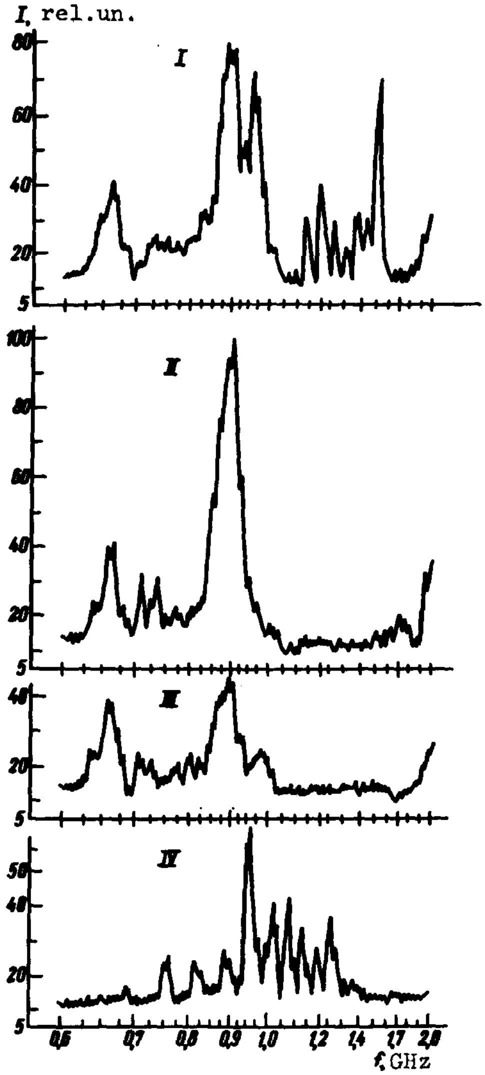

Fig. 2. Spectra of oscillations generated by a plasma-beam discharge. I, II, III - spectra at the beginning, middle, and end of the plasma chamber, obtained with probes. IV - spectrum of longitudinal oscillations.

Besides the probes, the longitudinal electric component of the oscillations propagating from the plasma via the electron beam was registered with the aid of broadband helical junctions located on both ends of the plasma chamber.

The experiments revealed generation of both transverse and longitudinal oscillations when the plasma density increased monotonically in the beam-injection direction, regardless of how and where these oscillations were received (the probes were located on both ends of the plasma chamber and in its center, and the helices on the two ends) in the entire investigated frequency band.

The frequency spectra of the oscillations picked off the plasma by a probe oriented along the E_r component of the field, in the range of the RVD resonant wavemeter (600 - 2000 MHz) are shown in Fig. 2 (I, II, III). The spectrum is quite broad and depends on the position of the probe along the beam direction. The spectrum of the longitudinal oscillations (Fig. 2, IV), picked off the helical junction located at the exit end of the plasma chamber, was similar, although somewhat more rarefied.

A plasma density gradient opposite to the direction of the beam propagation alters the picture of the oscillation radiation radically. No generation of transverse oscillations is registered by the probes at all, but longitudinal components are radiated. With decreasing magnetic field intensity, the amplitudes of the frequency spectrum decrease. To explain the experimental results, we note that, with the exception of the resonance region ($\omega \sim \omega_p \cos\theta$ at $\omega_H > \omega_p(z)$), the natural oscillations of the cold plasma at rest and the drift oscillations of the beam interact little and are described by the well-known dispersion properties (see [5]; ω, ω_H, and ω_p are respectively the perturbation frequency, the electron-Larmor frequency, and the electron Langmuir frequency, which vary along the axis of the interaction region; θ is the angle between the wave vector and the magnetic field). If the beam moves in the direction of a decreasing density, then the intensifying "cold" plasma mode propagates in the beam-motion direction (the group velocity is parallel to the phase velocity at ω) and is transformed in the vicinity of $\omega \sim \omega_p$ into a rapidly damped short-wave "hot" plasma wave [2, 3], for which propagation in vacuum is impossible. Accordingly, there is no pickoff of the energy of the transverse oscillations in such a propagation. It should be noted that if the plasma density changes noticeably over distances L comparable with the wavelength λ, then it is necessary to take into account the transformation of the waves in regions where geometrical optics is applicable in the first approximation in λ/L [2]. When the foregoing remark is taken into account, it becomes clear that when the beam (and consequently also the perturbation) moves in a direction of increasing density (i.e., when N^2 decreases), an appreciable fraction of the energy is transformed into waves that "flow out" from the plasma chamber to the outside. Such a transition is possible also when $N^2 > 1$. We note that when the beam moves in a direction of increasing density the quasilinear regime observed in [6] can lead only to an increase of the effect considered here, since the energy should go back to the beam in this case. In our case, owing to the strong inhomogeneity ($\lambda/L \lesssim 1$), this circumstance is apparently immaterial.

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DEPENDENCE OF THE ENERGY LOSS FROM A TOKAMAK PLASMA ON THE EFFECTIVE ELECTRON COLLISION FREQUENCY

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The current flowing through the plasma column in Tokamak devices performs the functions of heating and containing the plasma. Therefore the electron density n_e, the temperature T_e, and the current I are connected by a definite relation [1] and cannot always be varied in independent fashion. Such a possibility exists, for example, in a discharge with a relatively large initial hydrogen pressure, when the electron temperature at a given current is practically independent of the density in a wide interval [1]. Such a weak $T_e(n_e)$ dependence makes it possible to trace the variation of the transport coefficients with varying density or effective collision frequency ν_{eff}. The value of ν_{eff} is calculated from measurements of the electric conductivity of the plasma column and is nearly proportional to n_e, but unlike n_e this value takes into account the existence in the plasma of an uncontrolled amount of impurities or the development of collective processes.

Figures 1 and 2 show plots of $\beta_I = 8\pi n_e T_e/H_I^2$ (H_I - magnetic field of the current) and of the energy lifetime $\tau_E = (3/2)n_e T_e/(jE - Q)$ (j - current density, E - intensity of the longitudinal electric field, Q - power radiated