Propagation of electron cyclotron wave in a plasma-beam system

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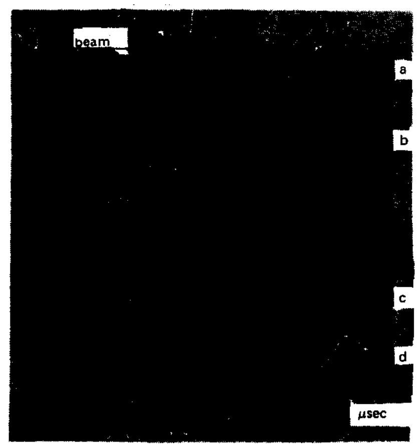
It is shown that the presence of a small fraction of hot electrons in a beam plasma exerts an appreciable influence on the damping of an electron cyclotron wave. The measured damping length is in good agreement with cyclotron damping on hot electrons.

When a high-power electron beam interacts with a plasma situated in an external magnetic field, a certain fraction of the electronic component of the plasma is heated to very high temperatures. In addition, the plasma produced in this manner has a high level of turbulence noise. The investigation of the propagation of an electron cyclotron wave (ECW) in such a plasma is of both purely physical and of practical interest, since a similar situation can arise also when the plasma is heated by a microwave of large amplitude. The point is that the presence of a small group of hot electrons and a high level of turbulence noise, with a frequency spectrum close to the wave frequency, can greatly influence the absorption of the microwave energy.

We have investigated experimentally the influence of a small group of hot electrons produced in a plasma-beam on the damping of the ECW in the frequency region $\omega_{He}/\omega = 1.5-2.5$. Since $\omega_{pl}/\omega \gg 1$ in our case, the noise at the plasma electron frequencies (ω_{pl}) should not affect the wave damping.

The investigations were made with the setup described in detail in[1]. The hot-electron plasma was produced in a magnetic trap with a mirror ratio 1.5 and a magnetic field in the homogeneous section up to 3 kOe, by passing through the neutral gas an electron beam with current up to 7 A and energy 20 keV. At a hydrogen pressure 5×10^{-4} mm Hg in the discharge chamber we obtained a plasma with the following parameters: plasma density $n_e \sim 2\times 10^{12}$ cm^{-3}, temperature of the main bulk of the electrons $T_{0e} \sim 10$ eV, temperature of hot plasma component $T_e^* \sim 20-30$ keV, and energy content $nT \sim 4\times 10^{14}$ eV/cm^3.

The ECW was excited with a Lisitano coil[2] or with the aid of a resonator operating in the TE_{111} mode; the coil or resonator was placed in one of the mirrors of the magnetic trap. The exciting elements were fed from a microwave generator of 200 W power at 3.8 GHz. The wave propagation and damping was investigated in the homogeneous section of the magnetic field. To prevent reflection of the microwave power of the wave, a "magnetic shore" could be produced at the end of the uniform section. The amplitude of the wave was measured with magnetic probes located near the plasma column at a distance $L \geq 50$ cm from the exciting element.



a--Electron beam current to collector; b--x-ray pulse with energy higher than 10 keV; c-- amplitude of $\tilde{H}_z$ component of wave; d-- signal blocking the sounding beam with $\lambda = 3.2$ cm.

The figure shows a series of oscillograms characterizing the variation of the amplitude of the $\tilde{H}_z$ component of the wave (Fig. c) as well as the evolution of the beam-plasma discharge in time (Figs. a, b, d) at $\omega_{He}/\omega = 2.5$. It is seen from thoese oscillograms that strong absorption of the wave is observed only in the presence of the x-rays due to the group of hot electrons of the plasma. Upon termination of the electron-beam current, the x-radiation decreases rapidly and the electron cyclotron wave attenuates practically without damping.

Measurements of the longitudinal wave number k_z have shown that it is not affected by the presence of a small group of hot electrons. At ω_{He}/ω the value of k_z was 2.6 in our case.

For comparison with the theory of collisionless cyclotron damping, we measured $\tilde{H}_z$ as a function of the length on the homogeneous section of the magnetic field at $\omega_{He}/\omega = 2.5$.

The damping length at the 5 A beam current at which the main parameters of the plasma were measured was found to be 30 cm. The measured damping length is in good agreement with that calculated from the formulas of[3] (p. 41) for the measured values $T_e^* \approx 20$ keV, $nT \approx 4\times10^{14}$ eV/cm^3, and $k_z \approx 2.6$. It is assumed here that nT is determined mainly by the hot component of the plasma.

It has thus been shown that if the plasma contains a small group of hot electrons (~1%) and $\omega_{He}/\omega = 1.5$–2.5, then the electron-cyclotron waves experience appreciable cyclotron damping and their energy is transferred to a small number of electrons; this is of considerable importance when it comes to heating a plasma with an electron cyclotron wave of large amplitude.

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