# LOW-FREQUENCY OSCILLATIONS OF THE PLASMA OF A CIRCULAR DISCHARGE IN CROSSED ELECTRIC AND MAGNETIC FIELDS

V. G. Andropov, N. A. Kruzhilin,
G. S. Lopatskii, and G. D. Petrov

UDC 533.951.2/3

Low-frequency oscillations in a circular discharge plasma are studied experimentally. Values of the magnetic field corresponding to the generation and collapse of ionization oscillations are determined. An analysis of plasma stability in the absence of ionization equilibrium is conducted. Agreement is noted between the theoretical and experimental results.

Low-frequency plasma oscillations in a contragyration discharge which was rotated in a magnetic field were studied earlier [1]. The existence of a circular form, when the discharge occupies the entire interelectrode space which leads to the closing of the azimuthal Hall current [2], is also possible. The generation and breakup of oscillations in such a plasma depends on the drift rate of electrons and ions relative to the neutral particles, determined by the magnetization of the corresponding components [3-5]. The present article is devoted to a study of the oscillations of such a magnetized plasma.

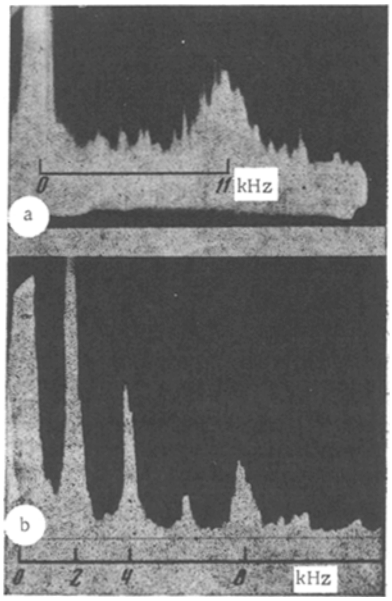


Fig. 1

The experimental setup is described in [1]. The gas pressure was 0.05-0.5 torr, the discharge current 0.05-0.4 A, and the magnetic field 0-3.5 G. The temperature and electron concentration were determined with measuring probes.

At a pressure of 0.1 torr these parameters were as follows:

| $H$, G | $I_d$, A | $T_e$, °K | $n_e$, $cm^{-3}$ |
|---|---|---|---|
| 0 | 0.39 | $2.18 \cdot 10^4$ | $1.13 \cdot 10^{10}$ |
| 50 | 0.38 | $2.47 \cdot 10^4$ | $1.38 \cdot 10^{10}$ |
| 100 | 0.375 | $2.67 \cdot 10^4$ | $1.48 \cdot 10^{10}$ |
| 150 | 0.37 | $2.78 \cdot 10^4$ | $1.92 \cdot 10^{10}$ |
| 200 | 0.36 | $2.82 \cdot 10^4$ | $2.13 \cdot 10^{10}$ |

The experiments showed that at a magnetic field lower than some critical value $H_* \approx 100$-140 G the amplitude of the pressure oscillations at the probes is small, while the frequency spectrum has the nature of "white noise." At the critical value of the field selective oscillations appear at a frequency of 11 Hz. The amplitude–frequency spectrum of oscillations of different probe potentials at H = 140 G is presented in Fig. 1a. At a magnetic field strength of 350-400 G the fundamental frequency of the oscillations decreased to 2 kHz and harmonics appeared at higher frequencies. The corresponding spectrogram at H = 380 G is presented in Fig. 1b. With a further increase in the magnetic field the oscillation frequency again increased. Analogous

Moscow. Translated from Zhurnal Prikladnoi Mekhaniki i Tekhnicheskoi Fiziki, No. 3, pp. 171-173, May-June, 1972. Original article submitted November 26, 1971.

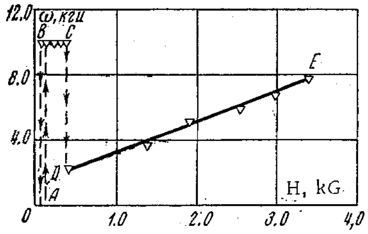


Fig. 2

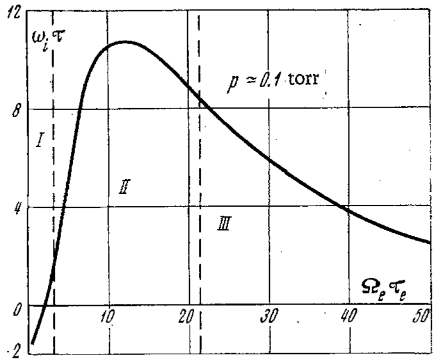


Fig. 3

behavior of the oscillation frequency was observed also from the brightness of the plasma glow.

The propagation rate of the oscillations in the azimuthal and radial directions was determined from the shift in the phases of the potential of the probes. The values lay within the limits of 100-200 m/sec. The characteristic size of the wavelength was on the order of 0.5-2 cm.

The dependence of the frequency of the first harmonic of the oscillations in plasma potential on the magnetic field is presented in Fig. 2. The regular oscillations arising when $H > H_*$ (section AB in Fig. 2) are caused by the instability of the initial state of the plasma. Oscillations related to ionization instability [3-10] show the greatest growth. The fact that the oscillations in electron concentration in section BC (Fig. 2) were fairly large and made up 10% of the mean value also points to the ionization instability. The oscillations in concentration were determined from the fluctuations in probe current and were independent of the fluctuations in the electric field [11].

A Hall electron parameter $\Omega_e\tau_e \sim 4$ corresponds to the appearance of regular oscillations (section AB in Fig. 2). The drop in the oscillation frequency (section CD in Fig. 2) is related to a value $\Omega_e\tau_e \gtrsim 20$, and at this value of the parameter the ion drift rate $\Omega_e\tau_e \cdot \Omega_i\tau_i$ is on the order of unity ($\Omega_i\tau_i$ is the Hall parameter for ions).

The dependence of the oscillation frequency on the magnetic field has a hysteresis nature (section AB in Fig. 2). With a decrease in the magnetic field the oscillations at 11 kHz are retained down to $H \sim 0.5\, H_*$, and then break up at $H \approx 40$ G, i.e., at $\Omega_e\tau_e \sim 2$.

An analysis of the dispersion equation of the ionization oscillations is of considerable interest. In deriving the dispersion equation a plane plasma layer of thickness L was considered, the direction of the current was assumed to be parallel to the XY plane, and the magnetic field along the Z axis. In the basic state the characteristic size of the nonuniformity in the plasma layer along the Z axis is on the order of L/2. Under the experimental conditions the production of electrons is caused by direct ionization, while electron losses are due to ambipolar diffusion and two-particle recombination. Electron energy losses are mainly due to thermal conduction processes, while losses by elastic and inelastic collisions can be neglected. Drift of the ions was calculated in a generalization of Ohm's law. The remaining equations had the standard form [6].

For oscillations with a wave vector parallel to the plane of symmetry (Z = 0) the dispersion equation has the form

$$i\omega_i\tau = 2h_1\left(\frac{k_xk_y}{k^2}\,\frac{\Omega_e\tau_e}{1+\varepsilon(\Omega_e\tau_e)^2} - \frac{k_y^2}{k^2}\right) - h_2\left(1+\frac{\varkappa_{e\perp}T_ek^2}{Q_0}\right) \tag{1}$$

$$h_1 = \frac{d\ln\tau_i^{-1}}{d\ln T_e}, \qquad h_2 = \frac{\tau_i}{\tau_r} + D_{a\perp}k^2\tau_i, \qquad \varepsilon = \frac{\Omega_i\tau_i}{\Omega_e\tau_e}$$

$$\tau = \frac{V_in_e}{Q_0}h_1 + \tau_i\left(1+\frac{\varkappa_{e\perp}T_ek^2}{Q_0}\right)$$

Here, $k_x$ and $k_y$ are wave vector components, $D_{a\perp}$ and $\varkappa_{e\perp}$ are the coefficients of ambipolar diffusion and electron thermal conduction across the magnetic field, respectively, $\tau_i$ and $\tau_r$ are the characteristic times of ionization and recombination [12], $V_i$ is the ionization potential of the gas, and $Q_0$ is the value of the Joule losses.

The dependence of $\omega_i\tau$ on $\Omega_e\tau_e$, calculated from Eq. (1), is presented in Fig. 3. The experimentally determined regions of the characteristic modes of plasma oscillations are also presented here. To determine the limits of stability from Eq. (1), we obtain an equation for the critical Hall parameter $(\Omega_e\tau_e)^*$

$$\frac{(\Omega_e\tau_e)^2}{[1+\varepsilon(\Omega_e\tau_e)^2]^2} = \frac{2h_2}{h_1}\left[1+\frac{h_2}{h_1}\left(1+\frac{\varkappa_{e\perp}T_ek^2}{Q_0}\right)\right]\left(1+\frac{\varkappa_{e\perp}T_ek^2}{Q_0}\right) \tag{2}$$

For $\Omega_e\tau_e < (\Omega_e\tau_e)^*$ the plasma oscillations are absent (region I in Fig. 3). For $\Omega_e\tau_e > (\Omega_e\tau_e)^* \approx$ 2–3 the value $\omega_i > 0$ and it is possible for ionization instability to arise (region II in Fig. 3). For $\Omega_e\tau_e > 10$ (a drift parameter on the order of unity) the parameter $\omega_i$ reaches a maximum and then decreases. For $H > 400$ G the oscillation frequency changes by jumps, which is evidently related to the establishment of another type of oscillations, most likely magnetoacoustical in nature.

## LITERATURE CITED


1. V. G. Andropov, G. S. Lopatskii, G. D. Petrov, V. I. Chernysh, and É. F. Yurchuk, "Low-frequency oscillations of a plasma rotating in a magnetic field," Zh. Prikl. Mekh. i Tech. Fiz., No. 5, 141 (1969).
2. M. F. Shirokov and E. P. Vaulin, "Flow of a nonisothermal plasma with high velocities," in: Investigations at High Temperatures [in Russian], Nauka, Moscow (1967).
3. S. Saito, N. Sato, and Y. Hatta, "Low-frequency oscillations in a weakly ionized plasma in crossed electric and magnetic fields," J. Phys. Soc. Japan., 21, No. 12, 2695 (1966).
4. A. A. Vedenov and E. P. Velikhov, "Problems of using a plasma with hot electrons in MHD generators," Electricity from MHD, Vol. 2, Vienna (1966), p. 395.
5. B. V. Eliseev, "Instability of pondermotive force in a weakly ionized plasma," Teplofiz. Vys. Temp., 2, No. 6, 852 (1964).
6. E. P. Velikchov and A. M. Dykhe, "Plasma turbulence due to ionization instability in a strong magnetic field," Compt. Rend. 6-e Conférence Internat. Phénom. Ionisat. dans Gaz, Vol. 4, Paris (1963).
7. J. L. Kerrebrock, "Nonequilibrium ionization due to electron heating. II" AIAA Journal, 2, No. 6, 1072 (1964).
8. I. Ya. Shipuk and S. V. Pashkin, "Plasma ionization instability in crossed fields," Dokl. Akad. Nauk SSSR, 176, No. 6 (1967).
9. A. M. Rozhkov, K. N. Stepanov, V. A. Suprunenko, V. I. Farenik, and V. V. Vlasov, "Resonance excitation of ion-cyclotron oscillations in a rotating plasma," Pis'ma v Zh. Éksperim. i Teor. Fiz., 10, No. 2 (1969).
10. A. F. Nastoyashchii, "Instability of a current in a transverse magnetic field," Teplofiz. Vys. Temp., 2, No. 3, 321 (1964).
11. G. S. Lopatskii and V. G. Andropov, "Characteristics of an arc discharge in a transverse magnetic field," Electricity from MHD, Vol. 2, Vienna (1966), p. 133.
12. L. M. Biberman, V. S. Vorob'ev, and I. T. Yakubov, "Theory of a nonequilibrium low-temperature plasma," in: Magnetohydrodynamic Methods of Obtaining Electrical Energy [in Russian], Énergiya, Moscow (1968), p. 209.
13. S. A. Trigher, "The theory of the stability of sound on a nonhomogeneous plasma," Electricity from MHD, Vol. 2, Vienna (1966), p. 409.