DYNAMIC CHARACTERISTICS OF A STRAIGHT TURBULENT DISCHARGE

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Plasma heating in straight turbulent discharges has been the subject of a number of investigations, but a clarification of the mechanism and dynamics of this phenomenon calls for more detailed research. The present communication is devoted to a description of experimental results obtained in an investigation of plasma heating by a straight-discharge current and concerning the dynamics of this process.

A block diagram of the setup is shown in Fig. 1. The initial plasma was produced by a Penning discharge in a quasistationary homogeneous magnetic field $H_0 = 1 - 3$ kOe. The electron density and electron temperature of the initial plasma were measured with an 8-mm interferometer and Langmuir probes, respectively. The main discharge was produced by discharging a capacitance C = 0.2 μF charged to a voltage $\tilde{U}_0 = 0 - 40$ kV. The distribution of the potential along the discharge was measured by Langmuir probes introduced from the side of the grounded electrode. The current density on the discharge axis and the energy distribution of the current electrons were measured with an electrostatic analyzer, also located in the grounded electrode. Resonant wave meters with λ = 3 - 100 cm, connected directly to the Faraday cylinder of the analyzer, made it possible to determine the spectral composition of the oscillations produced by the current flow.

It was established experimentally that the energy absorbed in the plasma, the current-voltage characteristics and active resistance of the discharge, the voltage drop on the column, and the spectra of the hf and lf oscillations all depend strongly on the parameters of the initial plasma and are determined, as a rule, by the ratio $\eta = j_{\sim}/j_0$. Here $j_{\sim} = \tilde{U}/\rho S$, where $\rho = \sqrt{L/C}$ and S is the cross section of the current channel, which depends on the skin processes during the initial stage, and $j_0 \approx en\sqrt{kT_e/m}$, where n_0 and T_e are the density and temperature of the initial-plasma electrons. If $\eta < 1$, the energy absorption is

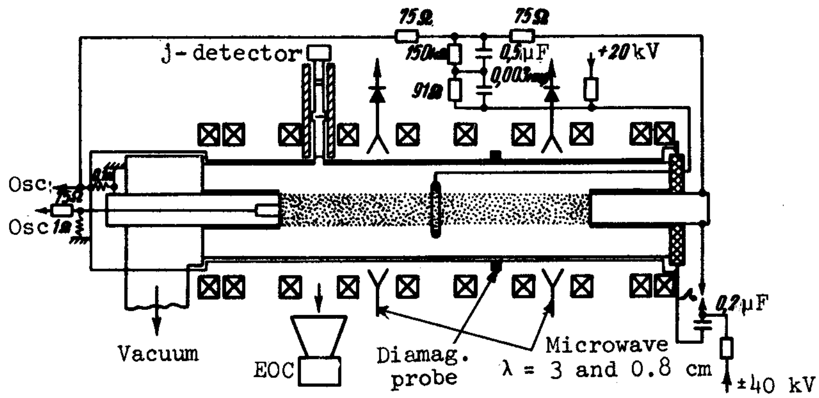

Fig. 1. Block diagram of setup

small and the potential as well as its distribution in the plasma are determined by the usual pair collisions and the boundary conditions on the electrodes.

A different picture is observed when $\eta \geq 1$. Figures 2a and b show typical plots of the main parameters characterizing the onset of the turbulent mode. First, before $\eta \lesssim 1$ is reached (this instant is marked by an asterisk in Fig. 2a), the current in the plasma is determined by the wave resistance. The condition $\eta \geq 1$ for the onset of turbulence was verified experimentally in the following manner. At a fixed voltage $\tilde{U}_0$ = 30 kV it was possible, by varying the initial-plasma condition, to vary electron density in the wide range $n_0 = 5 \times 10^{11} - 2 \times 10^{13}$ cm^{-3}, and a choice of the suitable delay of the main discharge made it possible to vary the electron temperature. The latter circumstance ensured a linear dependence of j_0 on the electron density.

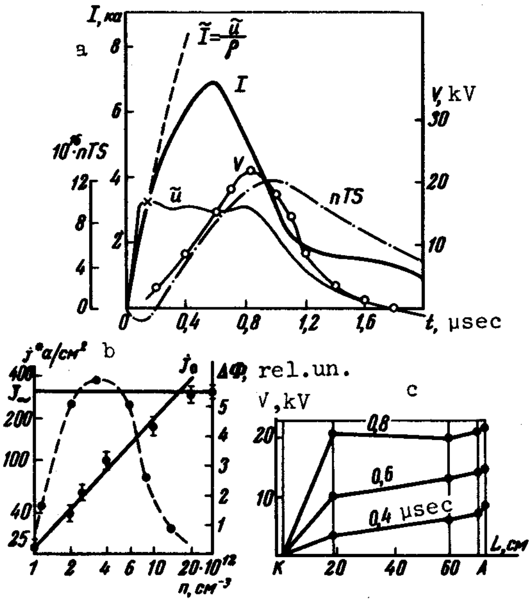

Fig. 2. a) Current-voltage characteristics of straight discharge. I - discharge current. Ũ and V - total and active voltage on plasma column. nTS - diamagnetic signal. Parameters: $n_0 = 2 \times 10^{12}$ cm^{-3}, $\tilde{U}_0$ = 30 kV, H_0 = 1.8 kOe, working gas - air. b) Critical current density j^* and diamagnetic signal vs. initial-plasma density. c) Distribution of potential along discharge.

Figure 2b shows the experimental value of the current density j^* in the plasma, corresponding to the onset of the turbulent mode. The same figure shows the dependence $\Delta\Phi = \Delta HS$ of the diamagnetic signal on the density of the initial plasma. It was established further that when $\eta \geq 1$ the onset of instability is accompanied by excitation of hf oscillations ($\omega \sim \omega_{0e}$) and lf oscillations ($\omega \geq \omega_{0i}$). At the same time, the active resistance of the plasma increases, causing the voltage on the column to increase (Fig. 2a).

It is seen from Fig. 2a that the power absorption and the diamagnetic signal increase simultaneously with increasing active voltage V. The effective collision frequency was determined from the plasma resistance, and also from the equation

$$\frac{ne^2}{m} E(z) + \frac{e}{m} \nabla p_e = j \nu_{eff} ,$$

where E(z) and ∇p_e were determined respectively from the potential distribution and the diamagnetic signal under the assumption that $p_\perp = p_\parallel$. It turns out that ν_{eff} varies in the range from 5×10^8 to 3×10^0 sec^{-1} at different stages of the instability, and agrees well with the observed spectrum of the lf oscillations and with its time dependence.

The dynamics of plasma heating as a result of the development of the instability is clearly illustrated by the measurement of the distribution of the current-electron energies, performed with a multigrid analyzer with a retarding potential. Figures 3a - c show the current oscillograms of the discharge and of the collector electrons at different values of the retarding potential. The delay curves plotted in a logarithmic scale (Fig. 3d) indicate that the electron spectrum is close to Maxwellian, and the discharge curent to the anode is apparently determined by the random electron current $j_a = env(T_e)/4$. By measuring j_a with an analyzer and determine T_e from the slope of the semilogarithmic characteristics, it was possible to estimate the density of the heated electrons. The following data were obtained for three instants of time:

$t_1 = 0.5$ μsec: $T_e \approx 1.2$ keV, $n \approx 1.2\times10^{12}$ cm^{-3};
$t_2 = 0.9$ μsec: $T_e \approx 2.1$ keV, $n \approx 1.4\times10^{12}$ cm^{-3};
$t_3 = 1.3$ μsec: $T_e \approx 3.0$ keV, $n \approx 5\times10^{11}$ cm^{-3}.

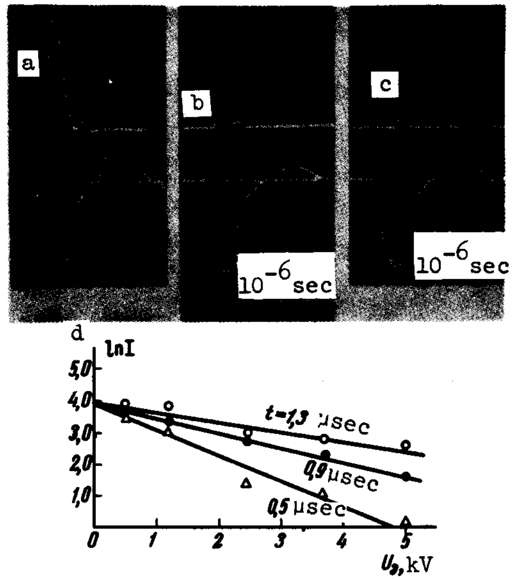

Fig. 3. Analyzer collector current vs. retarding potential. $\tilde{U}_0 = 10$ kV, $n_0 = 2\times10^{12}$ cm^{-} , $H_0 = 1$ kOe, working gas - air. a) $U_3 = 3$ kV, $j_{a\ av} = 90$ A/cm , $j_{a\ m} = 150$ A/cm^2, b) $U_3 = 2.4$ kV, c) energy distribution of electrons arriving and the discharge anode.

Consequently, it can be stated that as the current flow and the active voltage on the plasma increase, the value of $T_{e\parallel}$ increases and reaches it maximum at the instant of maximum energy absorption in the discharge. The density of the hot electrons turned out to be quite close to the density of the original plasma, and its decrease towards the instant of maximum heating is connected probably with the expansion of the plasma column. The transverse temperature $T_{e\perp}$ measured with a magnetic probe and with an x-ray detector by the interchangeable-filter method agrees satisfactorily with the value of $T_{e\parallel}$, both in magnitude in the character of the time dependence.

Thus, in the heating of a plasma by a straight-discharge current in our experiments, the dynamics of turbulence development was greatly incluenced by the parameters of the initial plasma. However, since mo measurements have been made as yet of the degree of randomness of the observed hf and lf oscillations, it is quite difficult to advance any opinions concerning the concrete heating mechanism.

A more detailed exposition of the results of the investigation of the dynamics of turbulent plasma heating in a straight discharge is scheduled for publication in the nearest future.

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