STABILIZATION OF A POWERFUL PENNING DISCHARGE BY A RADIALLY-INCREASING MAGNETIC FIELD

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We have studied the effect of a radially-increasing magnetic field, produced by a system of six rods with opposite direction of current flow in each neighboring pair, on the development of instabilities in a powerful Penning discharge with cold cathodes. It is shown that when the stabilizing system is turned off, the discharge is completely ionized and is highly unstable. The oscillations in the discharge occupy a frequency range from 10^4 to 3×10^7 cps. Turning on the stabilization system reduces the level of the oscillations due to instability of the discharge by at least two orders of magnitude. This is accompanied by a sharp reduction in the electron temperature in the discharge for a constant plasma density. It is concluded that the high values of T_e in Penning discharges are associated with the turbulent nature of the processes in the discharge.

WE have studied the effect of a radially-increasing magnetic field, produced by a system of six conductors with opposite direction of current flow in each neighboring pair,[1] on the development of instabilities in a powerful cold-cathode Penning discharge.[2-4] The instability of discharges of this type is due mainly to the azimuthal drift of the plasma in the crossed longitudinal magnetic field and radial electric field,[3] and also to excitation of oscillations in the plasma by the current of fast primary electrons emitted by the cathodes.[4]

A sketch of the apparatus is shown in Fig. 1. A quartz discharge tube 5 cm in diameter was placed in a uniform magnetic field H_0 = 600—1000 G. The length of the plasma column between the anodes was 40 cm, the diameter of the uniform part of the plasma column was 4 cm, the discharge current was 100 A, and the electrode voltage was 3 kV. The discharge electrodes were made of aluminum.

The plasma parameters were determined by means of movable Langmuir probes and from transmission of a microwave signal of wavelength 8 mm. The probe characteristics were analyzed by the method of Shulz and Brown.[5] The oscillations of electron density due to instability of the discharge, the motion of the discharge boundary, and the electromagnetic radiation from the tube were determined from the alternating component of the signal from the probes by means of a photomultiplier with a collimator and by a system of magnetic and electric antennas.

Measurements made with the stabilization system turned off showed that under the experimental

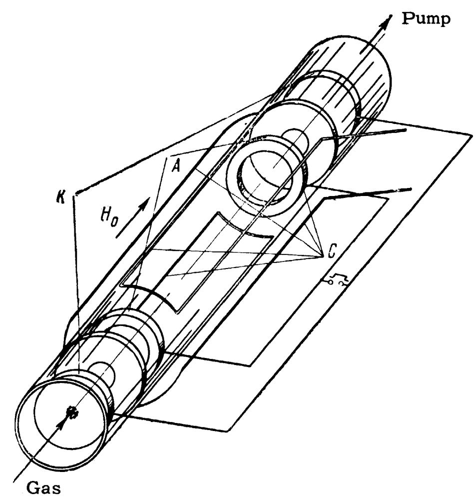

FIG. 1. Drawing of the apparatus: K – cathodes, A – anodes, C – stabilizing current conductors.

conditions the plasma was practically completely ionized, the electron density in the discharge was $(1—6) \times 10^{13}$ cm^{-3}, and the electron temperature fluctuated from 50—75 eV.

The measured spectrum of oscillations consisted of quasiharmonic low-frequency pulsations with a frequency of 10^4—10^5 cps and random noise pulsations in the frequency range 10^6—3×10^7 cps. The oscillation amplitudes of the discharge parameters due to the instability are comparable in value over the entire frequency range and reach several per cent of the equilibrium values of the density, intensity of emitted light, and so forth. The movable-probe measurements showed that the low-frequency oscillations can be identified with

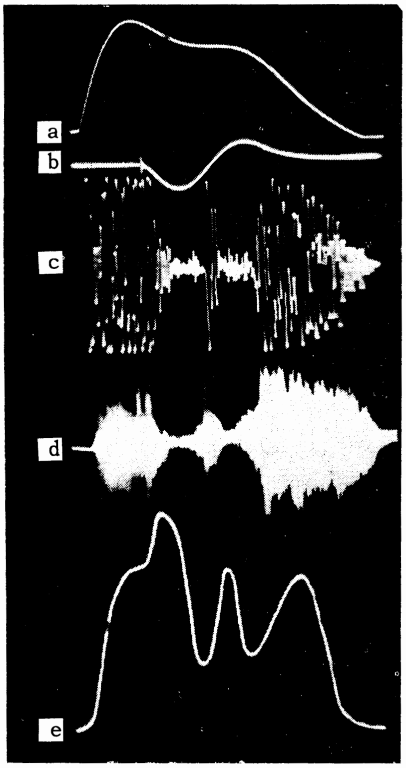

FIG. 2. Oscillograms of discharge processes (pressure 1×10^{-3} mm Hg): a – discharge current, amplitude 100 A, duration 500 μsec; b – current in stabilizer conductors; c – alternating component of current in the probe circuit; d – radiation from the discharge, axial component of the electric field; e – direct component of the saturation current in the probe circuit.

the previously observed[3] flute instabilities and with oscillations of the pinch as a whole about the equilibrium position. In the high-frequency region of the spectrum no spatial correlation of the oscillations was observed. Although an upper limit of the spectrum of fluctuations was not determined in the measurements, no appreciable radiation with wavelengths of 0.8, 3, and 10 cm was observed.

Figure 2 shows a series of oscilloscope pictures taken during a single discharge, characterizing the behavior of the main parameters of the discharge with the stabilization system turned on and turned off. We can see clearly the noise-suppression effect and the low-frequency component, separated by means of filters, of the oscillations in the discharge at the instants of the current peaks in the stabilizer wires.

Figure 3 shows the normalized instability current amplitude in the probe circuit as a function of the field intensity of the conductors $H_\perp$ at the plasma boundary, referred to the value of H_0. The critical value of $H_\perp$ agrees satisfactorily with the data on stabilization of flute instabilities given by Ioffe and Sobolev.[1]

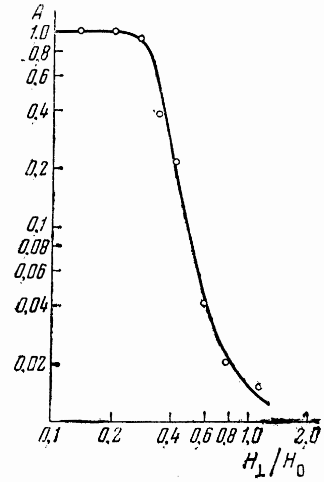

FIG. 3. Variation of the alternating component of the current to the probe with the ratio $H_\perp/H_0$.

An unexpected result of the experiments was the strong stabilizing action of the radially-increasing magnetic field on the high-frequency region of the spectrum of oscillations in the discharge. These oscillations are apparently associated with a two-stream instability[4] excited by the fast-electron current which maintains the discharge. The nature of this effect is not clear, since the stabilizing field acts only on the boundary region of the plasma column, while development of the two-stream instability is connected with processes in the entire volume of the discharge.

The sharp decrease of the saturation current in the circuit of the double Langmuir probe, which depends only on the plasma density and the electron temperature and which is observed at the time of turning on the stabilization system, should also be noted particularly. Analysis of the microwave and probe measurements shows that the effect is related to the sharp decrease in the electron temperature T_e in transition from the unstable discharge conditions to the stable conditions. The measured values of T_e in the stable regime are 3–5 eV and agree with the value of T_e in low-power weakly-turbulent discharges.[3] It is evident from the oscillograms that the decrease in T_e does not occur instantaneously but after a time of the order of 100 μsec, close to the value calculated by Spitzer[6] for the relaxation time of the energy of "hot" electrons in "cold" ions.

The weak variation found experimentally for the concentration and radial distribution of the electrons at the time of turning on the stabilization system indicates that in the processes of ionization and maintaining of discharges of the Penning type the principal role is played by the fast component of the primary electrons emitted from the cathodes.

At the same time the high values of T_e frequently noted in the literature and characteristic of such discharges are apparently due to the presence of the turbulent regime of the discharge.

It is of interest to determine the possibility of further increase in the electron temperature in discharges of this type and to capture electrons heated by this method into a field of mirror configuration.

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