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COMPARATIVE CHARACTERISTICS OF ELECTRON ENERGY SPECTRUM IN PIG AND ARC TYPE DISCHARGE PLASMAS

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16. Abstract The electron distribution functions relative to the velocity component directed along the magnetic field are compared for PIG and arc type discharges. The identity of these functions for the plasma region pierced by the primary electron beam and their difference in the peripheral part of the discharge are shown. It is concluded that the electron distribution function in the PIG type discharge is formed during one transit of the primary electron through the discharge gap. The mechanisms of electron energy spectrum formation in both the axis region and the peripheral region of the discharge are discussed.

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COMPARATIVE CHARACTERISTICS OF ELECTRON ENERGY SPECTRUM IN PIG AND ARC TYPE DISCHARGE PLASMA

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In studies of the electron distribution functions by velocity component parallel to the magnetic field ($v_{||}$) in a PIG discharge from an incandescent cathode [1], it has been shown that it differs significantly from Maxwellian in the axis region of the plasma, at electron energies $E=mv_{||}^2/2 \gtrsim 25$ eV. This difference is that, in the high electron velocity region, their number considerably exceeds the value corresponding to the Maxwell distribution. By analyzing the experimental results, we concluded that this excess of highly energetic particles, the spectrum of which reaches all the way to $E \approx 1.5$ eV_a (V_a is the discharge voltage), forms by means of effective scattering of the primary electron beam, resulting from collective processes to a considerable extent. The extent to which electron oscillations in a PIG discharge affects the form of their energy spectrum should have been determined. This could have been done by comparing the electron distribution function by velocity in a PIG discharge with the measurements of the functions for an arc type discharge under the same discharge conditions. The latter is understood to be a discharge, in which the deflecting electron is the anode, and the primary electrons complete a total of only one transit through the discharge system. The mechanism of formation of the nonMaxwellian part of the electron spectrum in the plasma outside the primary electron beam could also have been determined by such a comparison [1]. /1978*

The experiments were carried out in a discharge chamber, consisting of a 54 mm diameter cylindrical anode, bounded on one side by a flat indirect heating cathode, with a diaphragm collimating the electron beam to a 10 mm diameter and, on the other side, by a flat, 54 mm diameter deflecting electrode. The distance between the cathode and the deflecting electrode was 145 mm. All the results described below were obtained with a steady state discharge in a H=135 oersted magnetic field (if not separately stipulated), in helium at a pressure $p=2.6 \cdot 10^{-2}$ mm Hg. The voltage in the discharge was V_a=150 V and the discharge current I_a=0.37 A. To change the PIG discharge to an arc type discharge, the anode potential was fed the deflecting electrode, and the electrode previously serving as the anode

*Numbers in the margin indicate pagination in the foreign text.

remained under a floating potential. To investigate the electron distribution by velocity component parallel to the magnetic field, a five electrode electrostatic analyzer was used, located in the plane of the deflecting electrode. The electron velocity distribution function was determined by automatic differentiation of the electron blocking current reaching the collector of the analyzer. The layout and methods of measurement of the electron /1979 velocity distribution functions was previously described in greater detail [1].

The electron velocity distribution functions in an arc type discharge, obtained at various distances r from the system axis, are presented in Fig. 1. It can be seen that the electron velocity distribution function in the region of the primary electron beam (curve 3), both by the form of the highly energetic part of the spectrum (E>20 eV), and in general structure, hardly differs from that obtained in a PIG discharge [1]. Actually, from the results presented in Fig. 2, of a direct comparison of the two functions, taken for this region of the plasma in an arc type (curve 2) and PIG (curve 1) discharge , under the same discharge conditions, it follows that, in both types of discharge, the Maxwellian part of the spectrum extends all the way to an energy E≈20 eV, and a "plateau" region and more rapid decrease of $F(v_{\parallel})$ then follow. As is seen, in both cases, there is a substantial fraction of anomalously fast electrons ($E \gtrsim eV_a$), and no noticeable maximum, indicating its beam nature, is observed in the distribution functions.

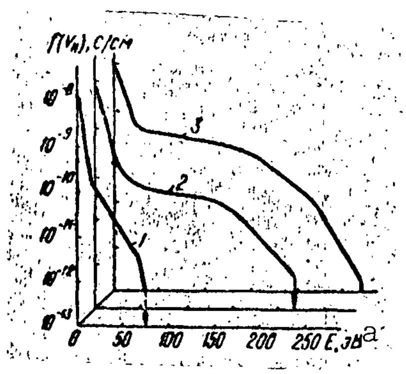

Fig. 1. Electron velocity distribution function in arc type discharge: 1. r=10 mm; 2. r=6 mm; 3. r=0.

Key: a. E, eV

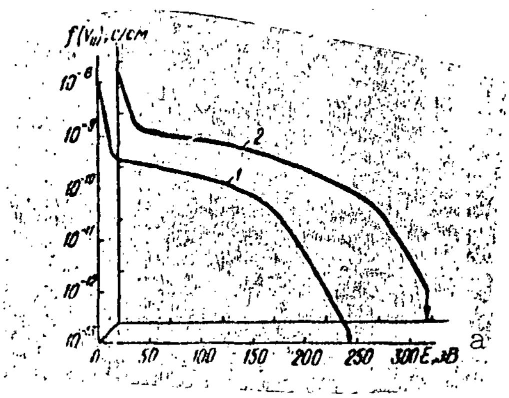

Fig. 2. Electron velocity distribution function in PIG discharge (1) an arc type discharge (2) on system axis (r=0).

Key: a. E, eV

It follows from the results presented above, that formation of the electron velocity distribution functions in both cases takes place in a single transit of the primary electrons through the discharge gap. Since the length of the latter is less than or on the order of the free path length of the primary electrons for pair collisions, such effective energetic scattering of them in both discharges can only be caused by collective interactions of the primary electron beam with the plasma. The energy spectrum of the anomalously fast electrons indicates the existence of a nonlinear mechanism of this interaction.

The studies showed that transformation of the electron velocity distribution function with radial distance from the system axis in an arc type discharge is significantly different than in a PIG discharge. The difference is that, in the arc type discharge, a sharper decrease in the limiting energy of the electrons recorded and fraction of the nonMaxwellian particles in the spectrum occurs, with distance from the primary electron beam, than in a PIG discharge. Thus, at a distance of 1 mm from it (curve 2, Fig. 1), the maximum energy decreases by approximately 50 eV, and the number of electrons with E=100 eV decreases approximately sixfold. With further increase in the distance, the fraction of fast electrons continues to decrease, the electron /1980 velocity distribution function approaches single temperature Maxwellian, and the maximum energy becomes much less than eV_a (see Fig. 1 curve 1). The latter never has been observed [1] in a PIG discharge, where the maximum energy always was at least eV_a. The results of a direct comparison of the electron velocity distribution functions, recorded under the same discharge conditions, at distance r=11 mm, for the arc type (curve 1) and PIG (curve 2) discharges, are presented in Fig. 3. They show that, besides the significant differences in the maximum electron energies in the spectrum indicated above, the relative number of fast particles is considerably less in the arc type discharge than in the PIG discharge.

It was proposed earlier [1] that the nonMaxwellian section of the electron energy spectrum, extending all the way to $E \approx eV_a$, in a PIG discharge plasma outside the primary electron column, can be due to either angular scattering or radial export of the particles from the axial region of the discharge, or by secondary ion-electron emissions from the end electrodes (diaphragm, deflector). The conditions for secondary ion-electron emission from the diaphragm in an arc type discharge are the same as in a PIG discharge. Therefore, the absence of particles with energies $E \approx eV_a$ in the peripheral plasma of an arc type discharge unambiguously indicates that the contribution of this effect to the electron energy spectrum in an arc type discharge and, consequently, in a PIG discharge, is negligibly small.

Only one single act of angular scattering of electrons inside the beam, which ejected them outside it, also cannot explain the type of energy spectrum in the peripheral region of the plasma in

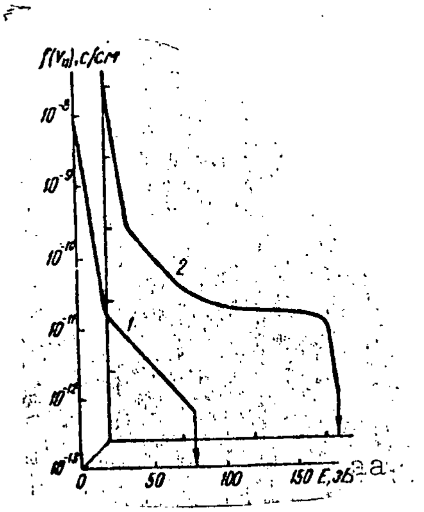

Fig. 3. Electron velocity distribution functions in arc type (1) and PIG (2) discharges outside the primary electron beam (r= 11 mm).

Key: a. E, eV

a PIG discharge, obtained at distances from the beam greater than the Larmor diameter of the particles. Evidently, the main factors which determine the type of spectrum in this region, at least of its high energy section, should be considered the radial flux of particles entering it from the plasma column penetrated by the primary electron beam and the accumulation of fast particles in the space, as a consequence of their oscillations. Actually, radial density and poten- /1981
tial gradients in a PIG discharge plasma, directed alike [2], essentially ensures the radial transport of electrons to the anode, if additional transport mechanisms connected with plasma instability [3] do not arise. These gradients are directed opposite each other in an arc type discharge [4], as a consequence of which, the radial transport of electrons is hampered and, moreover, there are no conditions for the accumulation of particles. This evidently explains the significant difference in the appearance of the high energy part of the electron spectrum of the arc type and PIG discharges noted above.

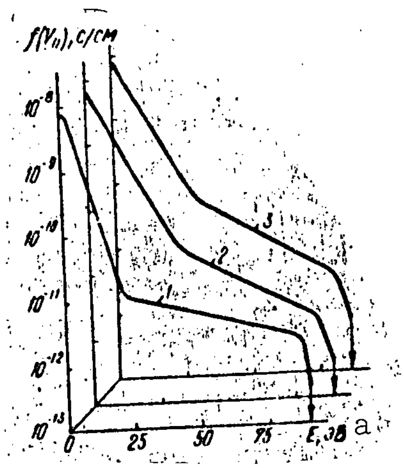

Fig. 4. Electron velocity distribution function in peripheral plasma (r= 16 mm) with different magnetic field strengths: 1. H=165 oersted; 2. 105; 3. 75.

Key: a. E, eV

Data on the transformations of the electron distribution function in the peripheral region of a PIG discharge plasma with increase in magnetic field strength, presented in Fig. 4, are evidence in favor of this point of view. It can be seen that, with increase in the magnetic field, both the temperature of the low energy, Maxwellian part of the spectrum, and the fraction of the high energy particles in the total number of electrons decrease. This is natural, since, with increase in the magnetic field, the radial transport velocity of the particles decreases, and they successfully lose their energy in the axial region of the discharge, as a consequence of which, it becomes "colder" on the periphery of the plasma. The absence of an appreciable number of anomalously fast electrons in this region of the plasma is connected with the fact that they form primarily in the primary electron beam, and they do not accumulate in space, since they leave by the end electrodes.

In summarizing what has been reported above, the following conclusions can be drawn.

The electron distribution functions by velocity component parallel to the magnetic field, in the plasma column region penetrated by the primary electron flux, are approximately the same in a PIG and arc type discharge under the same discharge conditions, and they are characterized by an excess (compared with Maxwellian distribution) of highly energetic, including anomalously fast particles. The results of work [5] become understandable in this connection. In it, considerable (on the order of V_a) potential drops were obtained in the plasma penetrating from the arc type discharge into the vacuum.

In both arc type and PIG discharges, the nonMaxwellian part of the electron velocity distribution function is formed by one transit of the electrons through the discharge gap, and the specific nature of the PIG discharge is reduced to the accumulation of particles with energies $E \approx eV_a$ in the space, due to their oscillation. The general structure of the electron distribution function in the PIG discharge evidently does not have to depend on the electron free path length for pair collisions, if the latter exceeds the discharge gap length.

The nonMaxwellian, highly energetic part of the electron velocity distribution function is caused mainly by collective interactions of the primary electrons with the plasma in both types of discharge. This interaction is localized primarily within the plasma column penetrated by the primary electron beam. The nature of the nonMaxwellian part of the electron energy spectrum outside the column is determined basically by the radial transport of particles and their accumulation in the space.

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