*Journal of Applied Mechanics and Technical Physics, Vol. 39, No. 5, 1998*

# GRID ELECTRODE IN A PLASMA JET

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UDC 533.9

*Scattering of plasma-jet protons by a strip formed by long parallel metal filaments was investigated. The strip is located perpendicularly to the jet at a distance of* 70 mm *from an ion extractor. Results of the experiment are adequately described by a model of a beam of noninteracting particles.*

The electric field generated by electrodes placed inside a plasma flow can be used not only for diagnostics of the plasma [1] but also for controlling the flow. For this, it is necessary to produce the electric field in a rather large volume without plasma failure. For this purpose, it is possible to employ grid electrodes. In the present work, the action of a grid electrode on a plasma jet is investigated experimentally.

A diagram of the experiment is shown in Fig. 1. Pulse arc plasma generator 1 ejects a plasma jet from the anode orifice. Inside the plasma flow [2, 3] moving from left to right there is grid 2 with a 0.5-mm step consisting of 10 heated tungsten wires of 30 $\mu$m diameter. An ion extractor in the form of a flat diode of grids 3 and 4 is located at 70 mm in the direction of the ion flow. Next there is an analyzer of the transverse angular distribution of ions, comprising recharging tube 5, slit collimator 6, and wire profilometer 7. A voltage of +7 kV is delivered to the anode of the plasma generator, and the electrodes, having contact with the plasma, are under a negative displacement of about −80 V relative to the anode. The displacement of the grid 2 relative to the anode is controlled. According to probe measurements, the plasma density near the grid was $2.8 \cdot 10^{10}$ cm $^{-3}$, the electron temperature was 2.1 eV, and the plasma potential relative to the anode of the source was −30.5 V. The plasma jet was a directed ion flow with a kinetic energy of about 30 eV at a transverse temperature below 0.1 eV. Pulse inflow of hydrogen into the discharge chamber of the plasma generator and into the chamber of the recharging target with a slight delay of arc discharge (less than 300 $\mu$sec from the beginning of the gas inflow) makes it possible to keep a rather low pressure (less than 0.1 Pa) in the plasma jet volume at the moment of measuring, and the ion scattering by the gas molecules is insignificant.

Linear profiles of a collimated beam of ions extracted from the plasma are given in Fig. 2. Profile 1 shows the angular scatter of unperturbed plasma ions, and profile 2 is the result of their scattering when the grid displacement is −70.5 V or when the grid potential $U$ is −40 V relative to the plasma jet. For scattered ions, the collimator and profilometer form an obscure chamber in which the angle of motion of protons and the site of their scattering in the plane of the grid are proportional. The valley at the center of the second profile is caused by scattering of protons by the grid filaments. The appearance of humps on the periphery of the profile is associated with the deflection of the particles by the edge field of the grid, because of which the particles arrive at the aperture of the analyzer. The trajectories of ions scattered by the positively and negatively charged grid are shown in Fig. 3. In the absence of shielding of the filaments and aperture restrictions, the ion scattering does not depend on the sign of the grid potential. At grid potentials $U < 20$ V of opposite polarity, the profiles coincided. For large values of $U$, differences appear which are illustrated by profiles 3 ($U = +20$ V) and 4 ($U = -20$ V) in Fig. 2. The difference in the profiles is caused by the action of the edge field which depends on the sign of the charge: it withdraws ions from the analyzer aperture or brings them

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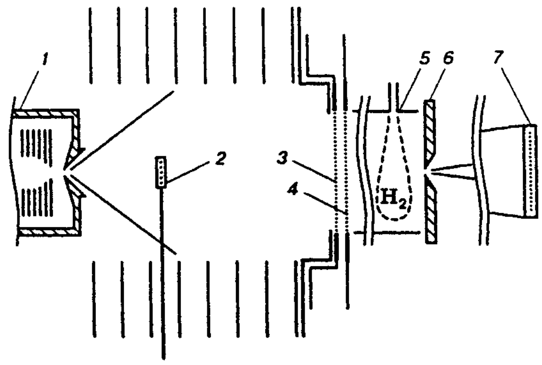


Fig. 1

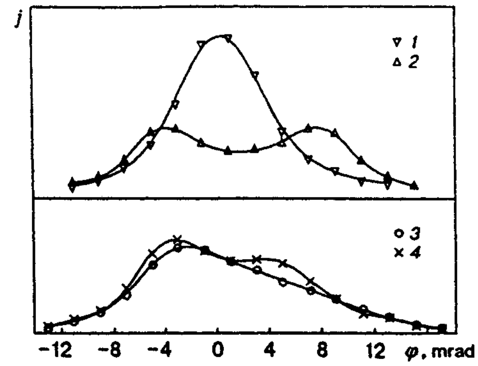


Fig. 2

Fig. 1. Diagram of experiment: 1) pulse arc generator of plasma; 2–4) grid; 5) recharging tube; 6) slit collimator; 7) wire profilometer.

Fig. 2. Linear profiles (1–4) of ions extracted from the plasma at potential $U$ equal to 0, −40, +20, and −20 V.

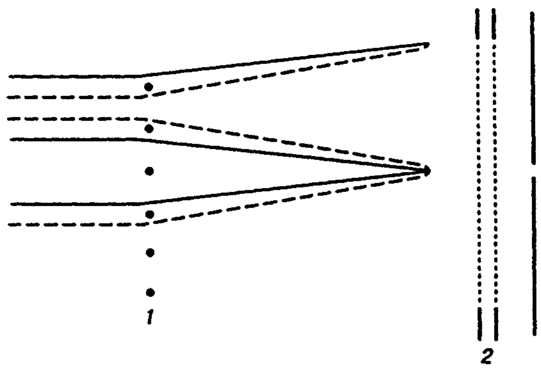


Fig. 3

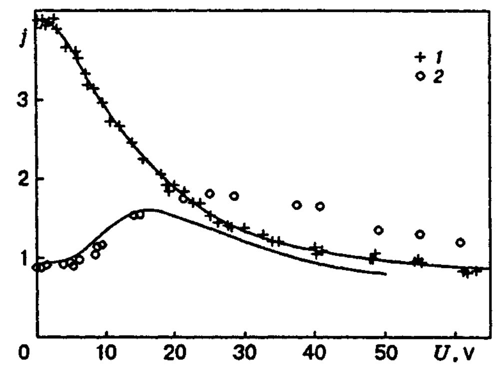


Fig. 4

Fig. 3. Trajectories of ions scattered by the positively and negatively charged grid 1 (solid and dashed curves, respectively); 2 — ion extractor.

Fig. 4. Density of the current of ions moving to the profilometer along the axis (points 1) at an angle of 3.1 mrad to the axis (points 2) at different grid electrode potentials; the curves are calculation results.

into it. The asymmetry of the profiles is connected to the position of the grid displaced by 1.5 mm from the axis.

To give a rigorous quantitative interpretation of the data, it is necessary to take into account that the plasma jet loses uniformity due to the perturbation introduced by the grid, and the interval of 70 mm between the grid and the extractor cannot be considered free from an electric field. But at a rather high grid potential ($U \gg kT_e/e \approx 2$ V), the ion motion is affected primarily by a large-scale electric field, which shifts the spectrum of transverse velocities of the ions but does not influence its shape. In the present work, the action of this electric field on the ions was ignored. For analysis of the experimental data, we used a model in which the grid scatters the flow of noninteracting ions with a certain initial spread of transverse velocities. The ion-scattering angle $\alpha$ is defined in a linear approximation by the formula

$$\alpha = \alpha_0(1 - 2x), \quad x \in (0, 1), \quad \alpha_0 = \pi\rho/\sqrt{VV_0}, \tag{1}$$

where $x$ is the ratio of the minimum distance from an ion to a filament to the step of the grid filaments, $\rho$ is the linear density of the charge of the filaments, and $eV$ and $eV_0$ are the kinematic energies of the ions expressed in electron volts in the plane of the grid and outside of the region of its action. The agreement between the model and the experimental data is illustrated in Fig. 4. It is evident that with a change in the potential $U$, the current of ions $j$ moving to the profilometer along the axis (points 1) and at an angle of 3.1 mrad to the axis (points 2) changes. The solid curves are calculated by formula (1), provided that the initial distribution of transverse velocities of ions is specified by the interpolated profile 1 (see Fig. 2), and the charge density $\rho$ is proportional to the potential of the filaments with a coefficient $c = 2.9$ pF/m ($V_0 = 29$ V). Good agreement between the model and the experimental data is obtained in cases where the aperture restrictions due to the finite dimensions of the grid are not manifested. The difference between the calculated curve 2 and the experimental points at $U > 20$ V indicates that the present simple model is not appropriate for the description of scattering at the grid edge.

The velocities of ions extracted from the plasma at a distance of 70 mm from the grid 5 mm wide perturbing the plasma jet are adequately described by the model of noncollisional scattering of ions. This implies that the result of collision of ions and the action of collective fields on them is insignificant compared to the effect of ion scattering by the grid. Under these conditions, it is possible to act on the phase volume of the ion flow by the grid electrode and to transfer it to a considerable distance by ions in the form of a beam of noninteracting particles.

The work is supported by a grant from the Ministry of Education of Russian Federation for fundamental research in the field of nuclear engineering and physics of beams of ionizing radiation.

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