INVESTIGATION OF HEAT FLUXES IN A PULSED PLASMA ACCELERATOR

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We determine the thermal state of the structure elements and estimate the energy distribution in a coaxial plasma injector operating under pulsed conditions. It is demonstrated that the insulator temperature affects the main parameters of the plasma jet.

The operation of pulsed plasma accelerators entails considerable energy losses [1, 2]. It is of interest to estimate the distribution of the energy and the amount of the loss in such a system.

An analytic determination of the energy loss is made difficult by the complexity of the processes in the accelerator, and an experimental estimate under single-pulse conditions is hindered by the short duration of the acceleration process.

We have investigated the distribution of the energy in a coaxial plasma accelerator of the erosion type using integral methods, and determined at the same time the influence of its temperature state on the accelerator parameters.

1. Experimental Setup and Measurement Procedure. The experimental model of the erosion-type plasma accelerator consisted of two coaxial electrodes separated by an organic-glass insulator (Fig. 1).

The internal electrode was made of copper, and the external one of steel with wall thickness 3 mm.

The accelerator electrodes were fastened directly to the corresponding leads of a 134 μF capacitor having a self-inductance 0.01 μH.

The accelerator together with the capacitor were placed in a vacuum chamber and mounted on one end of a torsion pendulum, making it possible to measure the draft force and practically eliminating the leakage of heat from the system by heat conduction.

The pressure in the chamber was initially $2 \cdot 10^{-6}$ torr, and did not exceed $2 \cdot 10^{-5}$ torr during the course of operation. The plasma accelerator operated periodically and the discharge was initiated with the aid of the system described in [3]. During the course of the accelerator operation, we measured the draft force and the temperature of the structure elements with the aid of Chromel–Alumel thermocouples (the numbers 1-7 in Fig. 1 indicate their location in the accelerator). The mass flow was determined by weighing the structure elements before and after the accelerator operation, and the data obtained were averaged over the number of discharge pulses. From the measured values of the draft and mass flow we determined the average plasma velocity and calculated the kinetic energy of the jet. The total plasma energy was measured with a calorimeter [4].

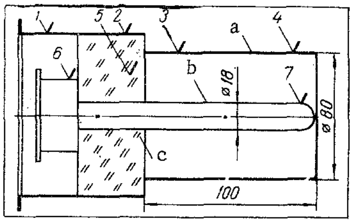

Fig. 1. Diagram of coaxial plasma accelerator: a) external electrode; b) internal electrode; c) insulator. 1-7) Locations of thermocouples on the structure elements.

2. Measurement Results. Figure 2 shows the measured temperatures of the structure elements as functions of the number of discharge pulses N when operating in the periodic mode. As follows from the curve, the magnitude of the thermal fluxes in the structure elements is practically independent of the number of discharges when $N > 10^3$ is reached.

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TABLE 1. Main Parameters of Coaxial Plasma Accelerator (N = 3500 discharges)

Discharge voltage, kV	Operating frequency, Hz	Energy consumption, W	Draft, g	Flow per second, g/sec	Average velocity cm/sec	Kinetic efficiency, %
2.0	1.2	322	0.28	$0.13 \cdot 10^{-3}$	$2.5 \cdot 10^{6}$	10

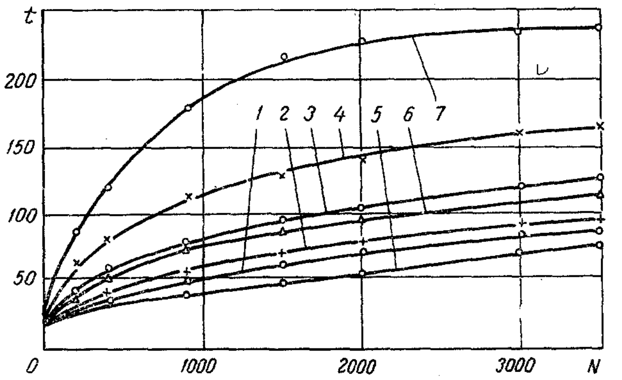

Fig. 2. Dependence of the temperature t (°C) of the accelerator structure elements on the number of discharge pulses N (cycles). The capacitor charging voltage is 2 kV, and the discharge repetition frequency is 1.2 Hz. (Curves 1-7 correspond to the numbered thermocouples in Fig. 1).

It was established that the character of heating of the accelerator elements is practically independent of the frequency of the discharge pulses, and is determined only by the total number of discharges. Table 1 lists the main parameters characterizing the coaxial plasma accelerator after N = 3500 discharges. In the same regime, an estimate was made of the distribution of the energy (per unit time, in W) fed to the capacitor plus accelerator system:

Initial capacitor-bank energy	322
Total plasma energy	110
Kinetic energy	32
Internal and thermal energy	78
Energy supplied	
to inner electrode	100
to outer electrode	70
Energy released in capacitor	42

The thermal fluxes in the structure elements were determined from the measured temperatures at different points of the corresponding elements. The internal and thermal energy of the plasma were determined as the difference between the total energy measured by the calorimeter and the kinetic energy of the jet. The loss in the capacitor was determined from the change of its temperature. To limit the heat flux from the accelerator to the capacitor, the electrodes of the discharge chamber were connected to the leads of the capacitor with eight RK-3 coaxial cables 0.7 m long. This hardly changes the characteristics of the discharge circuit, but there was practically no heat flow to the capacitor.

The investigations have shown that the total plasma energy and the draft do not depend on the number of discharge pulses in the series. However, the temperature of the structure elements of the accelerator increases with increasing number of discharges, causing an appreciable increase in the evaporated mass of the insulator, so that the average plasma velocity and the kinetic efficiency of the system are decreased (Fig. 3).

Starting with N $\simeq 10^3$ pulses, the velocity and the kinetic efficiency practically cease to vary with increasing N.

Thus, the experimental investigations have made it possible to estimate the heat fluxes in the structure elements of a coaxial plasma accelerator and to establish the energy distribution when the accelerator operates periodically.

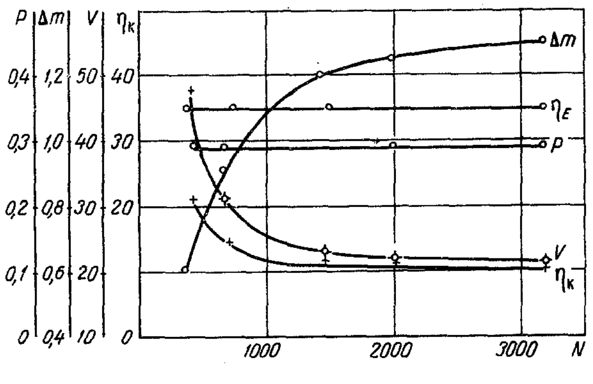

Fig. 3. Dependence of the draft P (in g), of the mass flow per second $\Delta m_{sec} \cdot 10^{-1}$ (mg/sec), the velocity V (km/sec), the energy efficiency η_E (%), and the kinetic efficiency η_K (%) on the number N of discharges (cycles) in the series.

The influence of the temperature state of the accelerator on its integral parameters has been determined.

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