PLASMA PARAMETERS IN A MAGNETOPLASMA COMPRESSOR IN THE COMPRESSION ZONE

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We report the results of an investigation of a magnetoplasma compressor using a bank of low energy ($\lesssim$ 30 kJ) but having parameters of practical interest, viz., quasistationary plasma lifetime $\tau \sim 40$ μsec, jet length $L \gtrsim 2$ m, jet macroscopically stable, flow divergence $\theta < 10°$, impurity concentration in the central compression zone $\alpha \lesssim 0.5\%$, $T_e \leq 11$ eV, $N_e \lesssim 5\times10^{17}$ cm^{-3}, and $W_i \lesssim 200$ eV. Regimes are observed in which half the energy fed to the discharge is released in the form of radiation (mainly in the vacuum ultraviolet).

The magnetoplasma compressor (MCP) principle was proposed in [1], and the existence of compression streams was demonstrated in [2, 3]. The considered MPC was fed from a bank of sixteen IM-5/150 capacitors. The compressor proper had a conically-cylindrical cathode (maximum diameter 12 cm) and 12 anode rods arranged in a circle of 22 cm diameter. The working medium was H_2 at a pressure P = 0.3 mm Hg. The discharge current and voltage are shown in Fig. 1b. Figure 1a shows a view of the plasma stream. We note that it is similar to that seen in the frames of high-speed photographs taken after the plasma configuration leaves the open end of the compressor [4]. The frames of the high-speed camera, the interference patterns [5], and the probe data indicate that the plasma stream as a whole is stable and is subject in the compression zone to only small swings with amplitude < 1 cm. It can be conditionally assumed that the central compression zone (CCZ) is ~6 cm long and its distance from the edge of the cathode is $z \sim 3$ cm. The most compressed part of the plasma has a diameter ~3 mm. The pinch divergence was determined from trails left on a target, the ion impurity concentration was determined from the absolute line intensity [9], the energy radiated by the compression zone was obtained with a semiconductor bolometer [10], and the translational velocity of the ions was determined from the Doppler shift of the spectral lines. To determine T_e and N_e we used photoelectric registration of the continuum intensity. The optical system was calibrated in the visible region against an SI8-200 lamp, which is used in astronomical research (its calibration error is 5%), and was calibrated in the near ultraviolet with a source having T = 36,000°, described in [7]. The MPC plasma satisfies the criteria for the applicability of the measurement method based on the decrease of the intensity of the continuum and its Balmer jump [6]. The continuum radiation was observed during the entire discharge, starting from the instant when the plasma configuration left the muzzle end of the cathode. During the time of passage of the plasma ($\tau \sim 15 - 18$ μsec), the integral intensity of the continuum exceeds the intensity in the quasistationary part ($20 < \tau < 55$ μsec) by 5 — 6 times. We chose for the measurement the interval $20 < \tau \leq 30$ μsec, in which the transient processes are already stabilized but the discharge current is still large enough. The intensity ε_λ of the continuum was measured at 3500, 4200, 4500, 5000, 5400, and 6000 Å. After stabelization of ε_λ to ε_λ = 4500 Å and ε_λ = 3500 Å we obtained the $T_e(\tau)$ distribution shown in Fig. 2. The density $N_e(\tau)$ was determined by measuring the absolute intensity of the continuum (λ = 4500 Å)

$$N_e = A_1\lambda\left[\frac{\epsilon_\lambda}{\psi(T_e)}\right]^{1/2}, \quad \text{where } A_1 = 1{,}6\cdot10^{15},$$

$$\psi(T_e) = e^{-hc/\lambda T_e}\left\{E_H^{1/2}T_e^{-1/2}g_{ff} + \frac{2}{27}E_H^{3/2}g_{fb}T_e^{-3/2}e^{\frac{E_H}{9T_e}}\right\}$$

g_{ff} and g_{fb} are the Gaunt factors [8]. The results of the determination of $N_e(\tau)$ are shown in Fig. 2. Detailed plots of $T_e(\tau, z)$ and $N_e(\tau, z)$ were obtained in the compression zone at a hydrogen pressure P = 1 mm Hg; they show that the maximal T_e^{max} and N_e^{max} in the quasistationary stage are determined by the discharge current I_d. For example, $T_e^{(max)}$ [eV] = $3\times10^{-4}I_d^2$ [kA]. A thorough comparison of the parameters obtained in the compression zone with those predicted in [1] calls for a detailed investigation of the entire flow picture in the MPC. The data obtained by us, however, suffice to calculate one of the main parameters of the theory, namely the polytropic exponent γ. Taking as the "initial" value the one measured in the compressor channel,

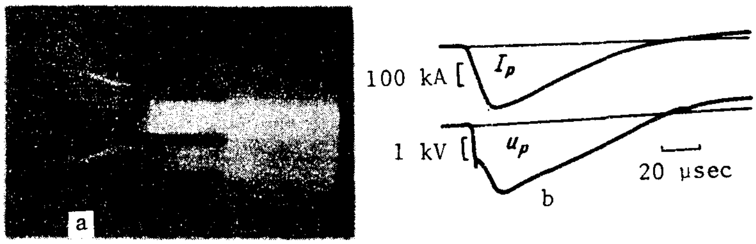

Fig. 1. a) Overall view of the discharge, b) discharge current and voltage.

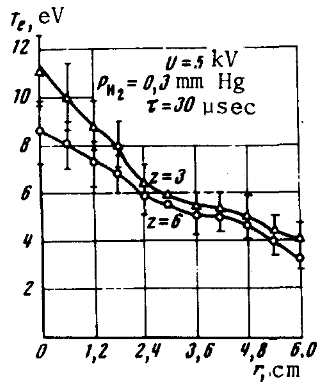

Fig. 2. The $T_e(\tau)$ distribution.

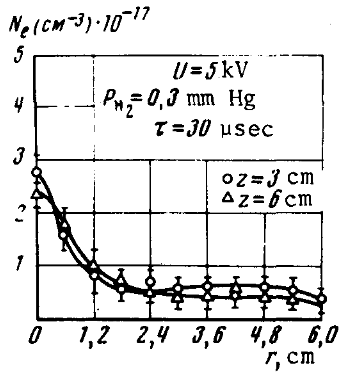

Fig. 3. The $N_e(\tau)$ distribution.

T_{e0} = 2 eV, and using the measured values (Figs. 2 and 3) of T_e^{max} and N_e^{max}, we obtain $\gamma \approx 1.5$. This does not differ greatly from the adiabatic exponent $\gamma = 5/3$. The lower value in comparison with the adiabatic exponent is due to the rather strong impurity radiation registered in the compression zone. It is also important to note that, as shown by calculation, the amount of impurities present in the compression zone suffices to explain the powerful vacuum-ultraviolet radiation. Thus, with a rather modest power supply, the MPC described here yields a narrow plasma pinch with parameters that are in agreement with one another and with the theory [1]. The MPC can be used as a plasma injector for high-power thermonuclear devices, as a high-power light generator, and in a number of other applications.

[1] A. I. Morozov, Zh. Tekh. Fiz. 37, 2147 (1967) [Sov. Phys.-JETP 12, 1580 (1969)].
[2] I. G. Linhart,
[3] A. I. Morozov, P. E. Kovrov, and A. K. Vinogradova, ZhETF Pis. Red. 7, 257 (1968) [JETP Lett. 7, 199 (1968)].
[4] A. I. Morozov, Vestnik AN SSSR, 1968.
[5] A. K. Vinogradova and V. P. Vinogradov, Paper at 1st All-Union Conf. on Plasma Accelerators, Moscow, 1971.
[6] S. Yu. Luk'yanov, Zh. Eksp. Teor. Fiz. 36, 1621 (1959) [Sov. Phys.-JETP 9, 1155 (1959)].
[7] N. N. Ogurtsov, I. V. Podmoshenskii, and M. I. Demidov, Optiko-mekh. prom. No. 1 (1960).
[8] H. Griem, Plasma Spectroscopy, McGraw, 1964.
[9] V. I. Berkov, R. E. Kovrov, et al., Paper at All-Union Conf. on Plasma Accelerators, Minsk, 1973.
[10] V. I. Berkov, ibid.