ELECTRODYNAMIC ACCELERATION OF PLASMA IN A COAXIAL ACCELERATOR

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Results of experiments on electrodynamic acceleration of plasma in a coaxial accelerator are presented and compared with theoretical data.

We will present some results of an experimental investigation of the process of electrodynamic acceleration of plasma in an accelerator of coaxial shape when the change of mass during acceleration is considered to be proportional to the coordinate.

The accelerator was made in the form of two coaxial electrodes of cylindrical shape with $b = 0.8 \cdot 10^{-7}$ H/m. Upon discharge of the capacitor battery the current I flowed in the circuit and interacted with the concentric magnetic field B of the central electrode. The ponderomotive force $F = [I \times B]$ arising as a result is always directed toward the outlet of the accelerating electrodes regardless of the direction of the current.

The battery of IMU-5-140 reservoir capacitors with a total capacitance of 280 μF was connected directly to the electrodes by means of a special coaxial system. A pressure below $0.5 \cdot 10^{-5}$ mm Hg was maintained in the vacuum chamber by continuous evacuation. The accuracy of measuring the pressure was of the order of 10%.

A simplified block diagram of the experimental device is shown in Fig. 1. The capacitor battery 14 was charged to initial voltages V_0 = 2-5 kV via charging resistors 10 from a high-voltage power source 6. The discharge was initiated by a spark between special electrodes 2 and the outer aluminum electrode 1 of the coaxial accelerator. A central copper electrode 3 served as the anode. Teflon was used as the insulator 4. The capacitors 11 of the special electrodes were charged via charging resistors 10 from a high-voltage power source 5. The instant of initiating the discharge in the accelerator was controlled by delivering a high-voltage pulse with a steep leading edge to the three-electrode discharger 15 from a special pulse-initiating unit 9 or using a SFR-2m "streak" camera. Overall control of the device was accomplished by the synchronization and control unit 7, and triggering of the sweeps of the oscillographs was done by a

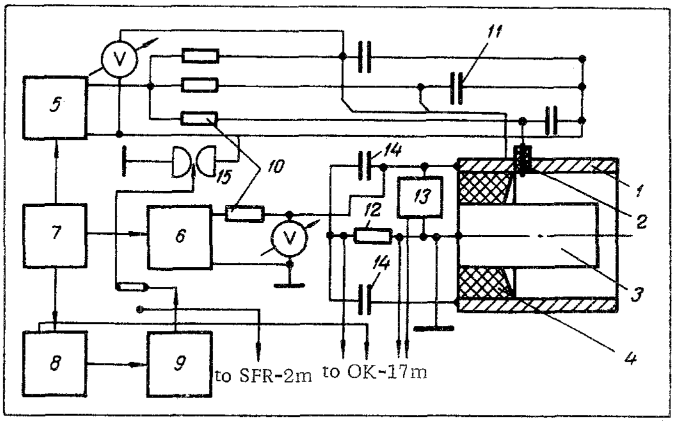

Fig. 1. Simplified block diagram of experimental device.

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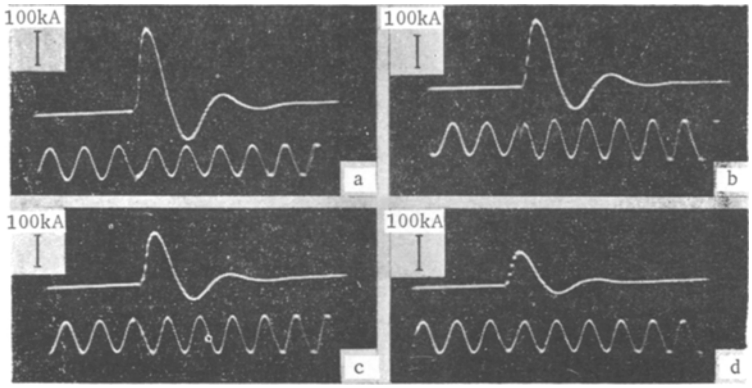

Fig. 2. Oscillograms of discharge current in coaxial accelerator. Frequency of sine signal 100 kHz. a) 5; b) 4; c) 3; d) 2 kV.

multichannel electronic time-delay unit 8. The current and voltage were measured by elements 12 and 13 of the device.

The inductance of the discharge circuit was $40 \cdot 10^{-9}$ H (with consideration of the inductance of the coaxial shunt).

The discharge current was measured by a low-ohmic coaxial shunt which was connected to the accelerator so that the coaxiality of the system was not disturbed, and its output voltage was delivered via cable to the plates of the OK-17m oscillograph. Figure 2 shows the oscillograms of the current for V_0 = 2-5 kV, and also the 100-kHz calibration sine signal. It is seen that the discharge exhibits an oscillatory aperiodic pattern and practically dies out by the end of the second period. The maximum values of the current were equal to: I_m = 246 kA for V_0 = 5 kV, I_m = 192 kA for V_0 = 4 kV, I_m = 149 kA for V_0 = 3 kV, and I_m = 98 kA for V_0 = 2 kV. The development of acceleration at the end of the coaxial accelerator in time was studied from the frames of the high-speed motion pictures taken by the SFR-2m camera under slow-motion conditions. Figure 3 shows the frames of such motion pictures for V_0 = 3 kV. The ejection of the plasma into the vacuum chamber occurs in the form of two bunches: a first bunch and a second bunch less intense in luminescence.

The velocity of the plasma was measured from the slope of the streaks of the photoscan of plasma propagation in the vacuum chamber. Photoscanning was also done with the SFR-2m camera under streak-camera conditions. The error of measuring the velocity was not more than 5%. Figure 3 also shows a photoscan of the luminescence of the first, more intense bunch, from which we see that the ejection of the plasma occurs in the form of individual plasmoids. On all photoscans the streaks have a maximum slope at the start of the discharge. The velocities for a time of order 4 μsec were respectively v = 48.5 km/sec for V_0 = 5 kV, v = 46.2 km/sec for V_0 = 4 kV, and v = 45.7 km/sec for V_0 = 3 kV.

A comparison of the experimental data obtained with the calculated data gives a satisfactory agreement, which is seen from Fig. 4. The curves I_{theor} and v_{theor} (Fig. 4) are the result of a numerical solution of a system of differential equations describing electrodynamic acceleration of plasma when the change of mass during acceleration is considered proportional to coordinate z:

$$m = m_0 + kz, \tag{1}$$

$$\frac{d}{dt}\left(m\frac{dz}{dt}\right) = \frac{b}{2}I^2 - K_p \rho S\left(\frac{dz}{dt}\right)^2, \tag{2}$$

$$\frac{dLI}{dt} + RI + V = 0, \tag{3}$$

$$L = L_0 + bz, \tag{4}$$

$$I = -C_0\frac{dV}{dt}, \tag{5}$$

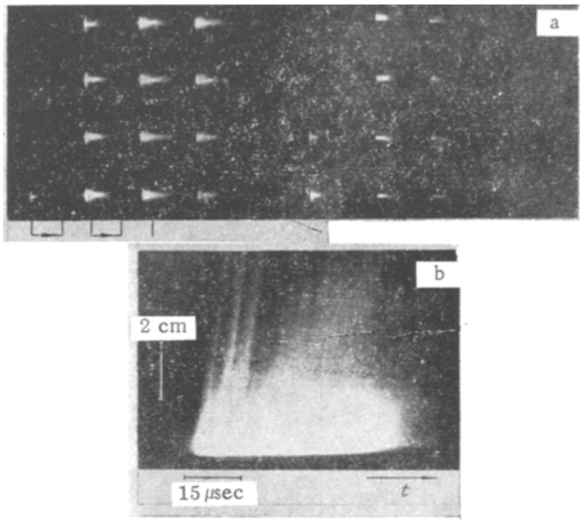

Fig. 3

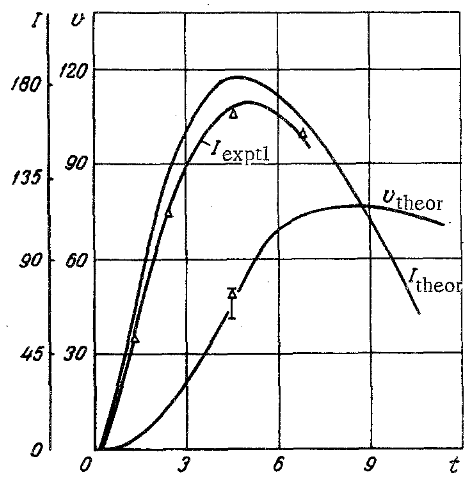

Fig. 4

Fig. 3. Frames of high-speed motion pictures of discharge of plasma in vacuum chamber (a) and a photoscan of the luminescence of the first bunch (b) for $V_0 = 3$ kV. The time between individual frames is 0.66 μsec.

Fig. 4. Change in time t of I_{theor}, v_{theor}, and I_{exptl} for $V_0 = 3$ kV, $C_0 = 280$ μF, $L_0 = 40 \times 10^{-9}$ H; I, kA; v, km/sec.

where Eq. (1) describes the change of mass during electrodynamic acceleration, (2) is the equation of motion under the effect of the forces of magnetic pressure (first term) and forces of resistance proportional to the square of velocity $(dz/dt)^2$ that arise, naturally, as a result of the change of mass according to law (1), Eq. (3) represents the balance of voltages in the circuit, Eq. (4) describes the change of inductance of the circuit during acceleration, and Eq. (5) is the determination of current in the accelerator.

The initial conditions for the solution of the system of Eqs. (1)-(5) for t = 0 had the form

$$\begin{gathered} V = 3\ \text{kV}, \quad I = 0, \quad m = m_0, \\ z = 0, \quad \frac{dz}{dt} = v = 0. \end{gathered} \tag{6}$$

The system of equations was solved numerically by the Runge–Kutta method, its parameters were selected in conformity with the parameters of the experimental device ($m_0 = 0.11 \cdot 10^{-7}$ kg, $R = 12 \cdot 10^{-4}\ \Omega$, $C_0 = 280$ μF).

The theoretical values of the discharge current (Fig. 4) are greater by an average of 10% than the experimentally measured values, and by 5% with respect to velocity for a time of order 4 μsec.

NOTATION

m	is the accelerated mass;
z	is the coordinate of the center of mass of the accelerated plasma;
I	is the current in accelerator;
I_m	is the maximum value of the current;
V	is the voltage across capacitor;
K	is the proportionality factor;
C_0	is the capacitance of capacitor battery;
L_0	is the initial inductance of circuit;
t	is the time;
K_p	is the resistance coefficient equal to 0.9;
b	is the distributed inductance per unit length of accelerator;
R	is the ohmic resistance of circuit;
ρ	is the density of undisturbed gas, expressed in arbitrary units;

v is the plasma velocity;
m_0 is the initial mass of accelerated plasma;
V_0 is the charging voltage of capacitor battery;
S is the area of middle section of plasma.

LITERATURE CITED

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