MEASUREMENT OF THE BRIGHTNESS TEMPERATURE OF A PLASMA PISTON IN RAILGUNS

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In accelerating macroparticles in railguns the electrically conducting pushing piston is a plasma formed with an electric explosion of a foil placed directly behind the dielectric body. To model successfully the interaction of this plasma with the accelerated body and the walls of the gun it is necessary to know the spatial and temporal distribution of the temperature in the plasma.

Direct experimental measurements of the plasma temperature are not described in the literature. Only simple estimates are made. Thus the numerical calculations of [1] give temperatures ranging from 30 to 60 kK, depending on the plasma resistance used. Numerical modeling, proposed in [2], gives a plasma temperature in the range 50-60 kK. Estimates of the temperature [3] based on the velocity of sound in the plasma give ~50 kK.

In this work we studied experimentally the brightness temperature of the plasma in a railgun.

Formulation of the Experiments. In experiments on the measurement of the brightness temperature of a plasma we employed a model railgun with a 17 × 9 mm rectangular channel cross section (the distance between the rails is 9 mm). The plasma was generated by means of an electric explosion of a copper foil 30 μm thick. A transparent glass window was made in one of the side insulators in order to perform optical measurements. The projectile was replaced by a dielectric plug, rigidly fastened between the electrodes. The energy source consisted of a capacitor bank.

The electrotechnical parameters of the circuit were chosen so that the curves of the currents in the experiments for measuring the brightness temperature were close to the curves of the currents in experiments on the acceleration of macroparticles [4]. The characteristic parameters of the current pulse were as follows: the amplitude ~400 kA and the rise time of the current up to the maximum ~50 μsec. The form of the current curve is shown in Fig. 1.

The brightness temperature of the plasma was determined by a photographic method [5], based on quantitative comparison of the brightnesses of the object of interest and a reference source with a known temperature in a narrow spectral interval based on the corresponding blackenings of the photographic material. The basic instrument employed for measuring the high plasma temperatures was a fast photochronograph with a rotating mirror. A narrow spectral interval was obtained by using interference light filters with a transmission halfwidth of 10 nm. Densitometric measurements of the photochronograms were performed on a photoelectric microphotometer.

The standard source with a known temperature consisted of the front of an air shockwave, propagating in a circular channel. The shockwave was generated by detonating a tubular explosive charge. For shockwave velocities 12-13 km/sec the temperature of the shock-compressed air plug equalled 20-25 kK.

Experimental Results and Discussion. Analysis of the photochronograms shows that the plasma formed with an electric explosion of a foil undergoes complex transformations under the effect of electromagnetic and gas-dynamic forces. Under the action of the flowing current the plasma is rapidly (within several microseconds) heated up to a temperature of 25-30 kK. The subsequent gas-dynamic expansion of the plasma against the forces of the magnetic field is accompanied by the formation of a low-temperature shroud, adjacent to the high-temperature part of the plasma. After 25-30 μsec the plasma separates into strata. The pattern of strata is complicated and irregular. The lifetime of separate strata

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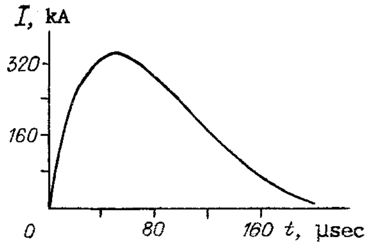

Fig. 1

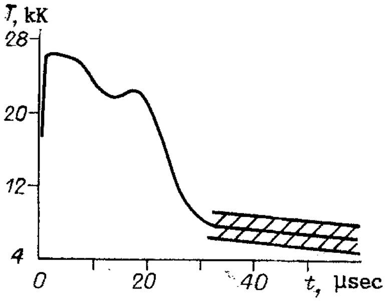

Fig. 2

fluctuates in the range 1-10 μsec. The number of such strata in our experiments cannot be determined and changes with time. The plasma temperature is different in different strata, but on the whole it is lower than the temperature of the plasma at the start of the discharge. It should be noted here that the question of the loss of transparency of the glass, through which the optical observation was performed, was not specially studied. Analysis of numerous experiments shows, however, that the glass remains transparent for no less than 30 μsec after the explosion of the foil in the railgun.

Figure 2 shows the time dependence of the brightness temperature from the results of five experiments. The measurements were performed at two wavelengths — $\lambda = 453$ and 548 nm — far from the resonance lines of copper radiation. Taking into account the 10% accuracy, all experiments gave identical values of the brightness temperature, which allows us to conclude that the plasma radiates as an absolutely black body. The cross-hatched part of the curve corresponds to the average temperature of the plasma after the plasma separates into strata. The quantitative value of the temperature in this part could be underestimated owing to loss of transparency of the optical window. The experimental values obtained for the temperature are significantly lower than the estimates of [1-3].

One can see from Figs. 1 and 2 that the time dependence of the brightness temperature differs substantially from the current curve. This is evidently attributable to the fact that at the start of the discharge the plasma occupies a quite small volume, and by the time the current reaches its maximum value the volume of the plasma increases significantly. Near the surface the plasma temperature could also differ from the temperature in the interior of the plasma. In addition, as already pointed out, the glass probably becomes opaque by the time the current reaches its maximum value.

For the maximum recorded brightness temperature the effective radiation flux ≈ 3 MW/cm^2.

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