ELECTRODYNAMIC FORCES AND PLASMA CONDUCTIVITY INSIDE THE CURRENT SHEET

S.Yu. Bogdanov, A.G. Frank, V.S. Markov
General Physics Institute, Academy of Sciences of the USSR
117942 Moscow, Vavilov st. 38, USSR

Studies of the rebuilding in magnetic field structure of a current sheet allow to reveal the nature of accumulation and consequent explosive release of magnetic energy. In the present report the distributions both of current density and of electrodynamic forces accelerating the plasma were determined on the basis of magnetic field measurements near the surface of the plane current sheet. The evolution of the plasma conductivity was also obtained.

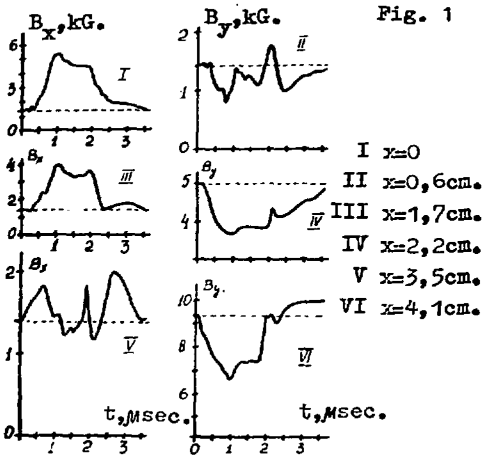
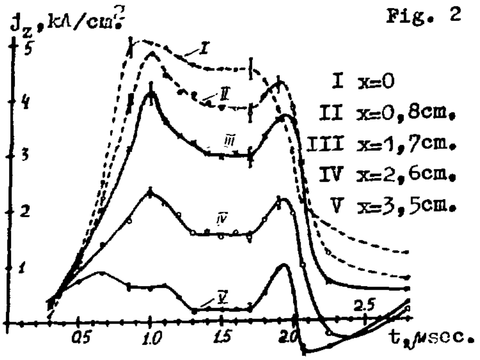


Fig. 1

In the experiments described the current sheet formation was caused by the high-current linear discharge ($J_z = 50$ kA) in two-dimentional non-uniform magnetic field $\vec{B} = h\{y;x;0\}$ with the gradient $h = 2.3$ kG/cm and null line on the axis Oz/1/. Neutral argon ($p = 10^{-2}$Tor) was ionized by means of preliminary discharge in the quasistationary magnetic field, after that the voltage ($E_z = 250$V/cm) forming the sheet was applied.

Six small magnetic probes were arranged on the line $y = 0.6$ cm near the sheet surface to record temporal variations of magnetic field/2/. Three probes ($x = 0;1.7;3.5$ cm) recorded the B_x-component parallel to the sheet surface, three other ($x = 0.6;2.2;4.1$ cm) recorded the transverse B_y-component. Fig. 1 shows the time behaviour of magnetic field at different points, the dashed lines representing the values of initial field without plasma current. The current densities averaged along the sheet thickness ($|y| \leq 0.6$ cm) were calculated under the assumptions, that the current distributions were uniform along z-axis and symmetric with respect to the planes $x = 0$, $y = 0$ /2/. The time behaviours of the calculated current densities at different points x along the sheet width are plotted in Fig. 2. The time dependence of the plasma current J_{sh} integrated over sheet cross-section (inside the region $|x| \leq 3.5$ cm, $|y| \leq 0.6$ cm) is shown in Fig. 3, also there are shown the independently measured total plasma current J_{tot} and the ratio J_{tot}/J_{sh}.

Fig. 2



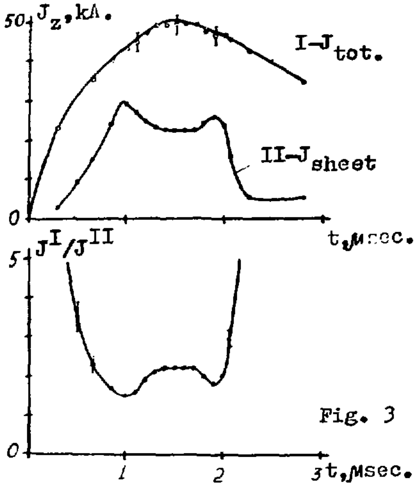


Fig. 3

During the sheet formation the ratio decreased and reached the minimum value ~ 1.5 at t = 1μsec. During following 0.4 μsec the rise of the total current was accompanied by a fall of the sheet current resultingly the ratio rise up to 2.2. We believe, that the decrease of current inside the sheet at this stage was caused by the increase of the sheet thickness. This effect was evidently displayed at the sheet edge x≃3.5 cm. Between 1.2-1.4μsec Bx-component was smaller than initially (Fig. 1), while the electric current near x = 3.5 cm, $|y| \leqslant 0.6$ cm had the same direction as the total current (Fig. 2) and therefore must increase B_x. This contradiction may be solved assuming that a current of the same direction appeared outside the region $|y| \leqslant 0.6$ cm. The simultaneous rise of the transverse By-component at x = 4.1 cm (Fig. 1) showed this current to be located at x > >4.1 cm. These changes in the current configuration demonstrates, possibly, that slow shock waves appeared near the sheet edges as it was obtained in numerical calculations /3/.

The estimates of plasma conductivity in the sheet center were done in /2/ without taking into account the velocities of plasma flows. Even this simple estimation allowed to reveal the correlation between the explosive disruption of the sheet and sharp decrease in the conductivity. The information about plasma velocities /4/ allowed more accurate values of conductivity and its time evolution to be obtained.

It is well known, that the change in z-component of the potential vector A at any point is described by the following equation:

$$\frac{\partial A}{\partial t} + (\mathcal{V}\nabla)A = -c\frac{\dot{j}}{\sigma}$$

On the basis of similar equations for the center and the edge of the sheet, it is easy to obtain the equation for plasma conductivity:

$$-c\frac{j_1}{\sigma_1} = \mathcal{V}_2^x B_2^y + \frac{\partial \Phi}{\partial t}$$

Here j_1 and σ_1 are the current density and plasma conductivity in the sheet center, $\mathcal{V}_2^x$ and B_2^y are the plasma velocity and the transverse component of magnetic field at the sheet edge, Φ is the magnetic flux crossing x-axis per unit length along z-axis. The values j_1, B_2^y, $\partial\Phi/\partial t$ were calculated on the basis of magnetic fields measurements, the typical values of V_z^x were obtained by the Doppler broadening of argon ion spectral lines /4/. The calculated values of electric fields, current densities and plasma conductivities in the sheet center for different moments are contained in Table 1.

Table 1: Plasma conductivity

t, μsec	0,75	0,9	1.05	1,15	1,45	2,05
$\frac{1}{c}\frac{\partial\Phi}{\partial t}$ v/cm	-20	-41	-8	52	-3	123
$\frac{1}{c} V_z^x B_z^y$ V/cm	85±12	120±12	85±12	53±12	74±12	240±60
E, V/cm	-65±12	-80±12	-75±12	-105±12	-70±12	-360±60
j_1 ,kA/cm^2	-3,7	-5,0	-5,0	-4,8	-4,5	-2,6
σ_1, 10^{13}sec^{-1}	5,1±0,9	5,6±0,9	6,0±1	4,1±0,5	5,8±1	0,65±0,1

Table 1 demonstrates that the $V\times B$ term mainly contributes into the value of electric field, while the term, caused by the flux variation $\partial\Phi/\partial t$, became essential only during the current decrease (t= 1.1; 2μsec). The plasma conductivity did not change during the time interval of existence of the quasistationary sheet,t = 0,7-1,5μsec, but it decreased about 10 times during the explosive disruption, t = 2μsec.

Plasma velocities were observed to be up to v_x = $3\cdot10^6$ cm/sec at the explosive stage /4/. This effect seems to be due to electrodynamic forces $f_x = \frac{1}{c}j_zB_y$. Using the data of magnetic measurements (see Fig. 1,2), it is possible to calculate the force at different parts of the sheet and at different moments, the results are summarized in Table 2. The force f_x avereged along X-axis (the last column) increased during the sheet formation (t < 0,7μsec) and weakly changed during both the stable stage and initial of explosive disruption (t = 0.7-2μsec) and then decreased at t = 2.25μsec. The dependence of f_x on x-position along sheet width was rather weak except t = 2,25μsec, when it altered the direction at the sheet edge, x = 2,6-3,5 cm. The typical plasma density in the stable sheet was about $N_e = 10^{16}$ cm^{-3}, and then decreased rapidly during the explosion /5/. The simple estimates make us conclude that electrodynamic forces calculated above could provide plasma acceleration up to velocities $v_x = 3\cdot10^6$ cm/sec only near the sheet edges in agreement with the data obtained in /4/.

Table 2:Electrodynamic forces, f_x, 10^6 dyne/cm^3

x, cm / t, μsec	0,8	1,7	2,6	3,5	$\bar{f}_x$
0,3	0,05	0,1	0,2	0,3	0,1
0,7	0,3	0,6	0,6	0,6	0,4
1,2	0,6	0,9	0,8	0,2	0,6
2,0	0,8	1,2	0,8	0,3	0,7
2,25	0,2	0,2	-0,1	-0,3	0,0

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