Break of the current sheath in a noncylindrical Z pinch

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(Submitted March 18, 1974)
ZhETF Pis. Red. **19**, 528–531 (April 20, 1974)

We consider the motion of a turbulization wave in the case when the magnetic field is determined by the discharge current. The motion of such a wave can explain the sharp increase of the velocity of convergence of the current layer in the "break" regime in a noncylindrical Z pinch.

In the study of a strong-current ($\sim 10^6$ A) discharge in deuterium with the "noncylindrical Z pinch" installation,[1] two regimes of the motion of the current sheath were observed. For the first regime, the "snow plough" (complete sweeping away of the gas) is valid after the instant of the maximum compression. The second regime of the motion of the current sheath is characterized by the fact that a compression radius ~ 10 cm there is a sharp increase of the velocity of the front of the current layer (break of the sheath).[2] The sweeping of the gas then ceases, as a result of which no dense plasma focus is produced on the chamber axis. The breaking phenomenon is accompanied by a powerful pulse of hard (~ 100 keV) x-radiation, which serves as evidence of the formation of an electron beam.

The breaking of the sheath is attributed in[2] to a deterioration of the conductivity of the plasma in the region of the contact with the anode, owing to the appearance of metal vapor. It is possible that this phenomenon indeed causes the breaking, but the ever increasing and very high compression velocity of the current layer in this regime ($\sim 10^8$–10^9 cm/sec) is evidence of a pure plasma mechanism of the subsequent breaking of the sheath, since the metal vapor have no time to penetrate to the required depth in the interior of the plasma.

In the present paper we do not explain the breaking of the sheath by using the onset of anomalous resistance in a plasma with a current flowing across the magnetic field. The possible mechanism of turbulization with appearance of anomalous resistance is the buildup of oscillations at the harmonics of the electron cyclotron frequency ω_H with a large increment $\gamma \sim \omega_H$ in the case when the current velocity of the electrons is of the order of or larger than the thermal velocity.[3] The anomalous conductivity of the plasma is determined in this case by the expression

$$\sigma = \frac{n_i e^2}{m(\nu_{\mathrm{Coul}} + \nu_{\mathrm{eff}})} = \frac{\sigma_{\mathrm{Coul}}}{1 + \omega_H \tau},$$

where the effective collision frequency is $\nu_{\mathrm{eff}} = \omega_H$.[3] An experimental confirmation of the turbulence in the current layer of a cylindrical Z pinch is the vanishing of the interference bands as a result of the anomalous scattering of the laser light.[4]

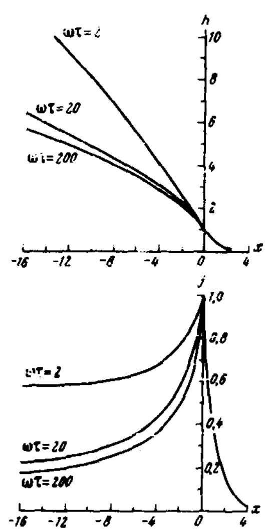
Under noncylindrical Z-pinch conditions, the current velocity of the electrons in the sheath can exceed the value at which the plasma becomes turbulized. In this case the increase of the resistance on the outer boundary of the sheath causes a redistribution of the current, towards its internal boundary, where the conductivity is of the Coulomb type. In turn, after the critical value of the current velocity is reached, an anomalous resistance is also produced here and the current again becomes redistributed in the interior of the pinch. The result is a current-density wave propagating towards the axis. The motion of this wave can be approximately described by the equation for the diffusion of the magnetic field in a medium with inhomogeneous conductivity, which depends on the value of the magnetic field

$$\frac{\partial \mathbf{B}}{\partial t} = \frac{c^2}{4\pi} \mathrm{rot}\left(\frac{\mathrm{rot}\,\mathbf{B}}{\sigma}\right), \tag{2}$$

where the plasma conductivity is given by

$$\sigma = \begin{cases} \sigma_{\mathrm{Coul}} & \text{in nonturbulent region} \\ \dfrac{\sigma_{\mathrm{Coul}}}{1 + \omega_H \tau} & \text{in turbulent region} \end{cases} \tag{3}$$

The turbulization region is assumed to be thin, since the increment is quite large $\gamma \sim \omega_H \sim 10^{11}\ \mathrm{sec}^{-1}$. In the planar case, Eqs. (2) and (3) have a self-similar solution, which is shown in the figure. The plasma has a Coulomb conductivity at $x > 0$ and an anomalous conductivity at $x < 0$. In the plane $x = 0$, a maximum current density is reached, and at this density the plasma becomes turbulized. The current wave and the boundary separating the Coulomb and turbulent plasma move to the



Distribution of magnetic field (h) and of the current density (j) in the case of motion of a current wave at different $\omega_H\tau$.

right with a velocity

$$v = \frac{u|_{x=0}}{\omega_H \tau}, \quad (4)$$

where $u|_{x=0} = j|_{x=0}/n_e l$ is the current velocity on the separation boundary.

As a result of the motion of the current wave, the entire plasma column becomes turbulent, even though the current velocity of the electrons, calculated from the total number of particles in the plasma-column cross section, can be much less than required for instability development with subsequent turbulization simultaneously over the entire cross section of the column. In the cylindrical case, the cumulation of the current wave on the axis leads to a sharp increase in the amplitude of the current density and to the possibility of electron-beam formation. Calculations on cylindrical cumulations will be published separately.

The authors thank N.V. Filippov for a discussion and for support.

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