OSCILLATORY STRUCTURE OF A QUASI-STATIONARY MHD SHOCK WAVE IN A PLASMA

G. G. Dolgov-Savel'ev, V. K. Malinovskii, and Yu. E. Nesterikhin

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A great amount of attention is presently being devoted to the structure of collisionless shock waves in a plasma [1,3]. It has been shown theoretically and experimentally that when $\omega_{Hi}\tau_i \gg 1$ and $\omega_{He}\tau_e \gg 1$ ($\omega_{Hi,e} = eH/m_{i,e}c$ is the Larmor frequency for ions and electrons and $\tau_{i,e}$ is the free-flight time) the wave has an oscillatory structure. Here the space scale of the oscillations is of order c/Ω_0 (where $\Omega_0^2 = 4\pi ne^2/M$) when the direction of wave propagation does not have a significant transverse component with respect to the direction of the magnetic field.

All of the past experiments, however, deal with nonstationary shock waves. Similar studies of collisionless waves in a plasma have been performed for the almost stationary mode for the flight of artificial satellites around the earth; in this case, the interaction between the solar wind and the earth's magnetosphere is studied. Unfortunately, there is still an incomplete set of experimental data.

To study the structure of a shock wave the authors constructed an instrument containing a plasma injector [4] and a Michelson interferometer as the chief elements.

The shock wave was generated by the supersonic flow of a rarefied plasma stream around an object. This object was a cylinder 10 mm in diameter and 80 mm long. The plasma stream moved in a direction perpendicular to the cylinder.

The light source for the interferometer was a ruby laser working in the pulsed-Q mode for frame photographs and in the quasi-continuous-generation mode for chronographic sweeps. The frames photography made it possible to obtain a picture of the flow with an exposure of $2 \cdot 10^{-8}$ sec. The plasma density distribution as a function of time and stream velocity was found by chronographic sweeps of the interference pattern.

The temperature of the electron component was measured from the scattering of the laser radiation on the plasma.

The following parameters were used in these experiments for the working part of the plasmoid: $n_{0e\max} = 5 \cdot 10^{15}$ cm^{-3} is the maximum electron density; $T_{0e} = T_{0i} = T_0 = 4$ eV is the plasma temperature; $v = 9.3 \cdot 10^6$ cm/sec is the directed velocity of the stream.

The length of the working section of the plasmoid was about 10^{-5} sec in a time scale such that the condition that the process be quasi-stationary ($\tau^\circ \gg L/v$, where τ° is the length of the working section of the plasmoid; L is the dimension of the body; v is the directed velocity of the stream) had a very large margin of error.

Hydrogen was the working gas. The plasma injector and plasma gun were placed in a longitudinal magnetic field whose strength could be varied from 0-3 kilogauss. Here the plasmoid parameters could be held to within 10%.

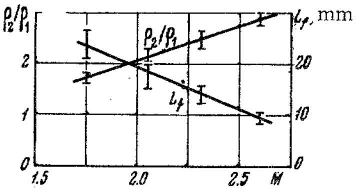

Fig. 1

We studied the width of the wave front as a function of magnetic-field strength. In the presence of a magnetic field the effective Mach number is

$$M_{ef} = \frac{M_0}{(1+\beta/\gamma)^{1/2}} \qquad \left(\beta = \frac{H^2}{8\pi p_0}, \quad \gamma = \frac{c_p}{c_v}\right).$$

Here $H^2/8\pi$ is the magnetic pressure; p_0 is the plasma pressure; c_p and c_v are the specific heats at constant pressure and volume, respectively; M_0 is the Mach number of the stream for $H = 0$.

When $\beta < 1$ the magnetic field does not noticeably affect either the nature of flow or the structure of the shock wave. In this case the width of the front is on the order of a few times the width of the mean free path.

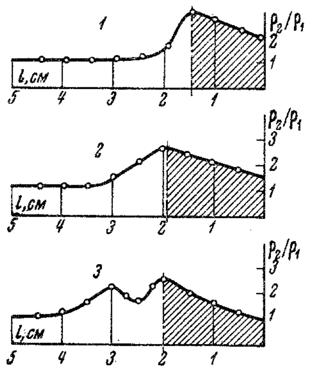

Fig. 2

For larger magnetic fields ($\beta \geq 1$) the width of the discontinuity increases, the wave intensity decreases, and the angle increases between the shock wave and the direction of the stream (Fig. 1).

For $\beta \sim 1$, practically the only effect of the magnetic field is to change the effective Mach number of the stream. A further increase in β leads to an qualitative change in the form of the shock-wave profile. Figure 2 shows the change in density as the front of the shock wave is passed through as a function of the quantity β; wave profiles 1, 2, 3 correspond to $\beta = 0, 1, 2$. As is clear from Fig. 2, an increase in magnetic pressure results in the appearance of an oscillatory wave structure.

Theoretical studies [6] applying to the limiting case $\beta \gg 1$ predict that because of dispersion effects an oscillatory trail moving ahead of the oblique wave will appear in the presence of a magnetic field; this trail has a space period

$$\lambda = c\Omega_0^{-1} \sin\theta , \qquad (1)$$

where θ is the angle between the normal to the plane of the wave front and the magnetic field. The oscillations attenuate over a length

$$\Delta = c\Omega_0^{-1}\, \omega_{He}\tau_e \sin^2\theta . \qquad (2)$$

We can expect Eq. (1) to be valid for finite β above some critical value when Joule dissipation begins to exceed viscous dissipation.

In these experiments, $\sin\theta \sim 1$ for $\beta \geq 2$, i.e., the condition $\omega_{He}\tau_e \gg 1$ will be a condition for the existence of the oscillatory mode. For $\tau = 2$ (Fig. 2) we have $\omega_{He}\tau_e = 6$ and $\lambda \sim 8$ mm. The calculated value for c/Ω_0 is 3.0 mm; this value is in satisfactory agreement with experiment to within an order of magnitude.

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