Nonliniar Processes and Extreme States in Plasma Produced by Electroexplosion of Miniature Tungsten Ring[1]

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Abstract – The nonlinear ultra fast phenomena in plasma produced by electroexplosion of miniature tungsten ring (~50–80 μm in diameters) driven by nanosecond pulse of high current (~150 kA) are numerically investigated. It is shown that a nonlinear solitary waves "shooting vortex" with strong magnetic and electric fields, high temperatures and pressures can be generated during such electroexplosion. The complicated fine structures of magnetic fields involved opposite poles are observed.

1. Introduction

This paper is a continuation of work [1], at which we consider processes of matter transitions into extreme states accompanying by nonlinear phenomena and try to answer on the fundamental questions connected with the problem of nonlimited cumulation [2]. The considered case is similar to experiments [3], at which in magnetic z-pinch with character diameters of plasma channels (in neck) $d \sim 100$ μm (driven by 150 kA current with 1.1 μs pulse duration, at low inductance $L \approx 1$ nH) 3 hot spots and short pulses of X-ray radiation had been detected as well as a magnetic field with helical structure and small plasma spheres. In present computer simulation we assume that throw tungsten ring with internal diameter $d_1 = 50$ μm and external diameter $d_2 = 80$ μm a high current flows with time pulse form of total current $I(t)$: for the line growth during 15 ns from 0 to 60 kA, then I is constant during 35 ns, then after 50 ns – a new line growth during 15 ns up to 150 kA, then again I is constant during 35 ns, and finally – the line decreasing up to zero during 15 ns (as in [4]). The 2D radiative MHD code URAGAN-XY [5] in plane geometry (some modification of ZEVS-2D code) had been used in computer simulation with taken into account an all main physical properties of real matter (including properties of strongly coupled plasma, properties plasma with two temperatures, viscosity, influences of strong magnetic fields, radiation processes and heat transfer).

2. Results and Discussions

In this report a normal dynamics of pinch system as well as ultrafast nonlinear processes will be considered. Here we can shortly consider some peculiarities only. The first one is a "shooting" soliton (or vortex) generation. The main plasma parameters at time $t = 14.55$ ns are represented on Figs. 1, 2. It is seen that extremely high ion temperature can be in such vortex. All current (at this time $I \approx 58$ kA) goes throw hot spot (with lifetime $\tau \approx 36$ ps), and ring wire is not destructed at this time. It is interesting that analogous hot plasma with temperature range $T = 1$–5 MeV had been predicted in [6] for "laboratory fireball" produced by intense laser beam (at a range of intensities peaking at $\sim 3 \cdot 10^{20}$ W/cm^2). Note, that in practices the generation of analogous system (similar to miniature black hole) had been already realized in [7] without using of super high power laser system. We used a picosecond laser beams with initial intensities in range $\sim 5 \cdot 10^{13}$–10^{15} W/cm^2 and set nonlinear effects (for example, effect of optimal filtration and etc.).

The shooting vortex can be generated in turbulent plasma with a high energy density after current action (see, e.g., Figs. 3–8). The needed energy can be accumulated in magnetic tubes as well as in fine structures like as in solar plasma [8] (see, Figs. 6, 7).

3. Summary

A strong shooting vortex can be generated in electroexplosional plasma as in laser-induced discharges. Its properties are very similar to the properties of miniature black holes, at which the generation of exotic quasiparticles can take place due to processes of quantum evaporation [7]. This, in turn, is a nonlinear solution of the main problem considered in [2]. The considered phenomena can take place in different plasma systems with high energy densities, for example, in strong nuclear explosions, lightnings, sprites and etc. This computer simulation must be verified in modern experiments, but for my opinion, the first successful electrodischarge experiments in this area were already produced by Nikola Tesla.

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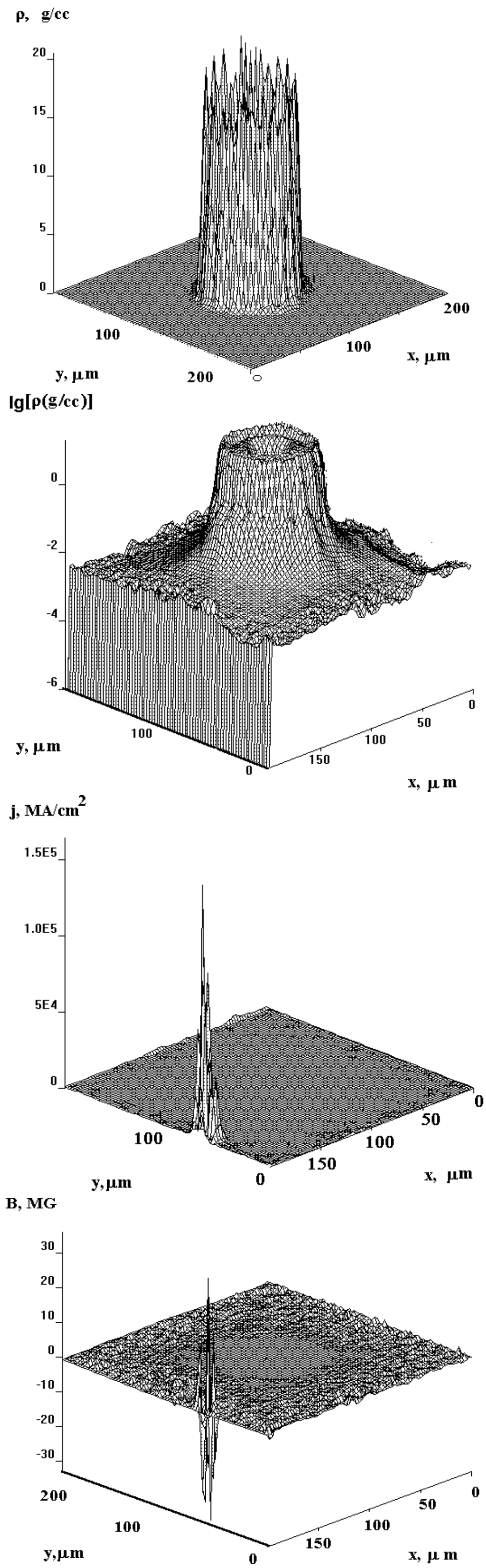

Fig. 1. The matter density $\rho(x,y)$, current density j, inductance of magnetic field B at t = 14.55 ns

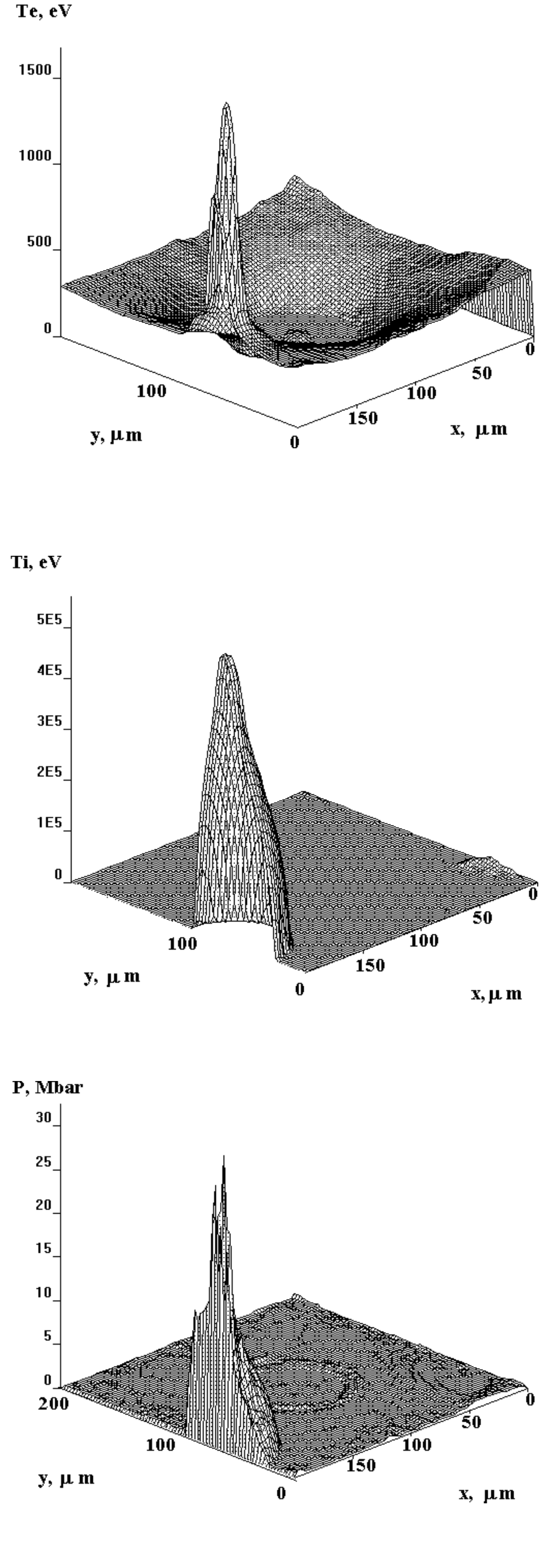

Fig. 2. The electron and ion temperatures T_e, T_i, and the total pressure $P(x,y)$ at t = 14.55 ns. There is a minimum density of plasma in the center of hot spot $\rho \sim 10^{-6}$ g/cc.

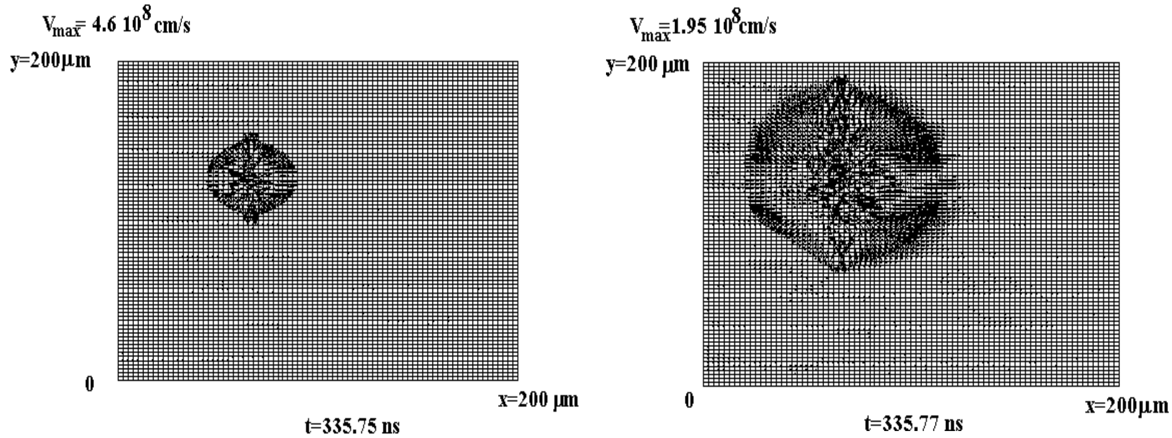

Fig. 3. The field of velocities at different times

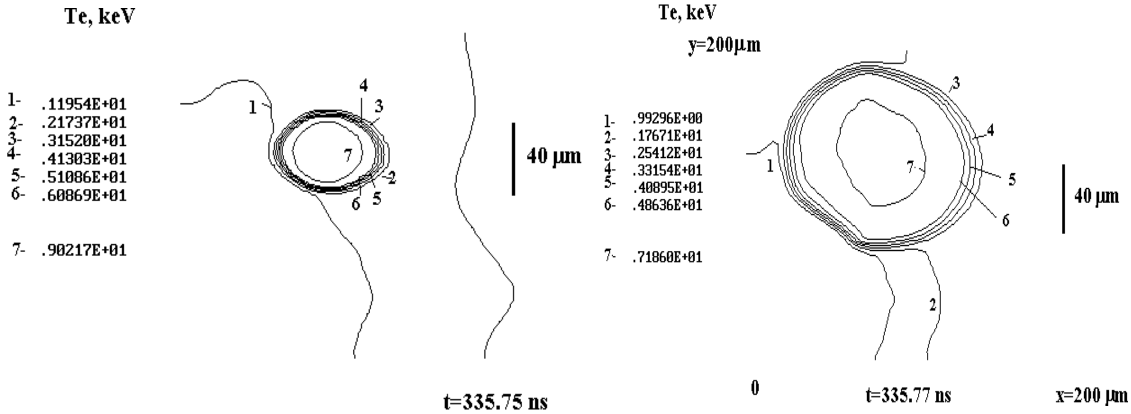

Fig. 4. The electron temperatures for different times

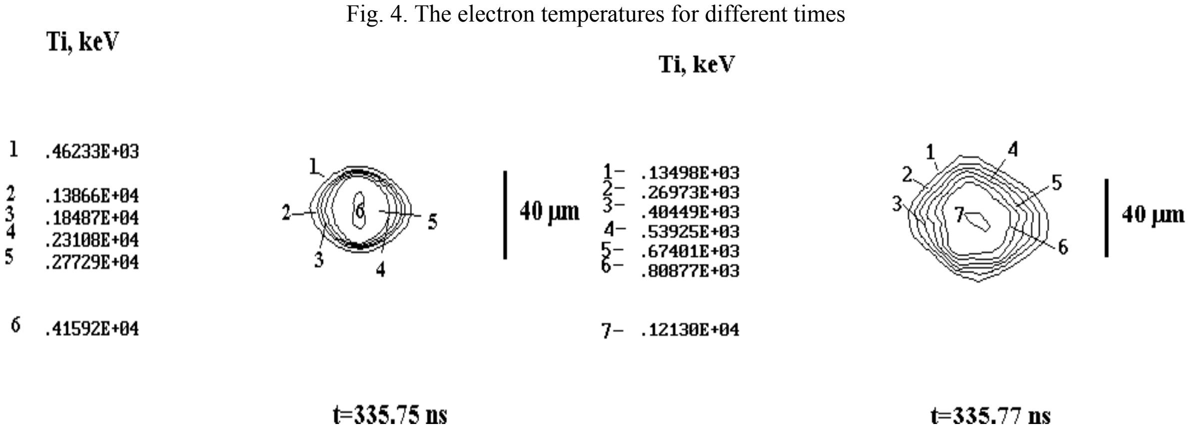

Fig. 5. The ion temperatures at different times

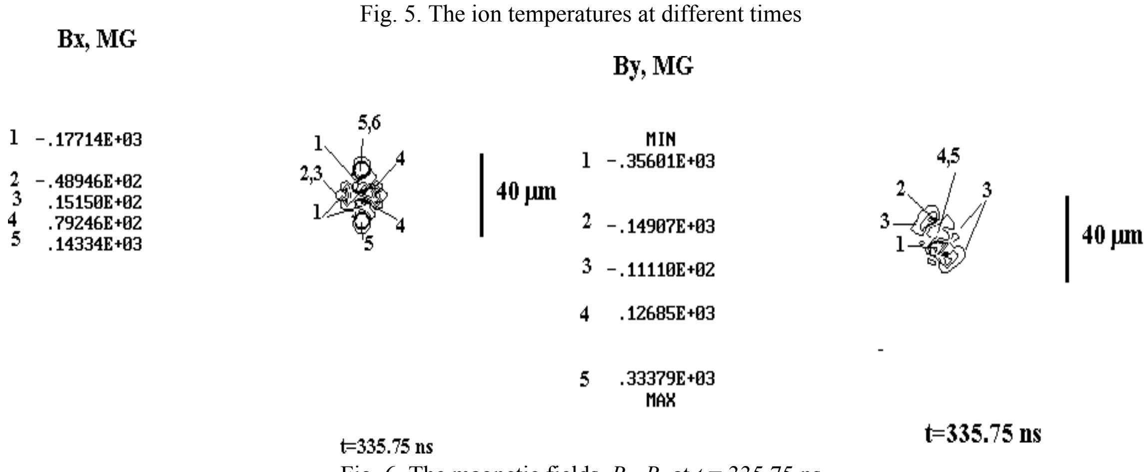

Fig. 6. The magnetic fields, B_x, B_y at t = 335.75 ns

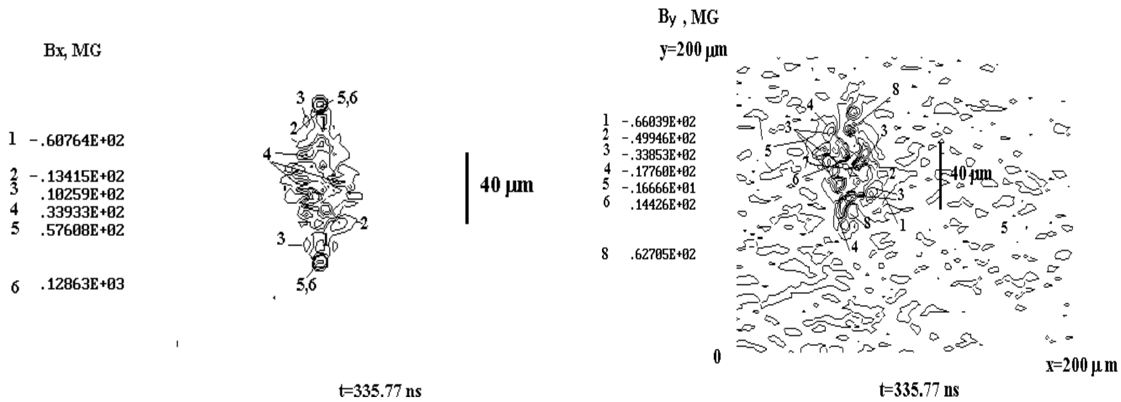

Fig. 7. The magnetic fields, B_x, B_y at t = 335.77 ns

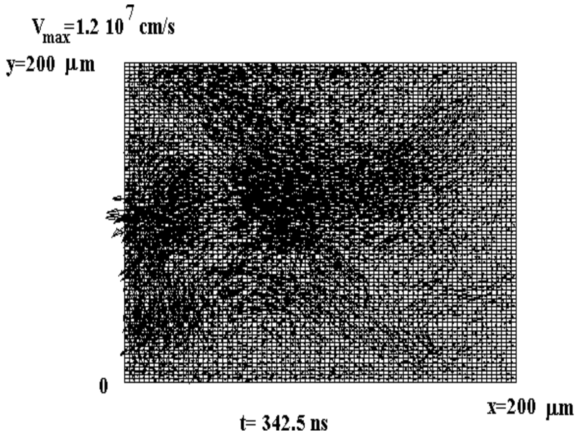

Fig. 8. The field of velocities at later time t = 342.5 ns

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